HIGH-TENSION POWER TRANSMISSION

A Series of Papers and Discussions Presented at the Meetings of the American Institute of Electrical Engineers, under the Auspices of the Committee on High-Tension Transmission

REPUBLISHED BY THE
McGRAW PUBLISHING COMPANY
NEW YORK
By Special Arrangement with the
American Institute of Electrical Engineers
1905

HIGH-TENSION TRANSMISSION COMMITTEE

1902-1903

RALPH D. MERSHON, *Chairman*
F. O. BLACKWELL
C. C. CHESNEY
P. M. LINCOLN
C. L. CORY

1903-1904

RALPH D. MERSHON, *Chairman*
F. O. BLACKWELL
C. C. CHESNEY
P. M. LINCOLN
A. M. HUNT.

PREFACE

At a meeting of the Board of Directors of the American Institute of Electrical Engineers, held September 26, 1902, the following resolution was passed:

"*Resolved*, That a Committee on High-Tension Transmission, consisting of five members, may be appointed for the purpose of collecting data respecting present practise in electric transmission at high voltage, and of presenting a report which will indicate the successful methods which are now in operation in such form as to be of immediate value to electrical engineers. It is within the scope of the Committee to secure data upon line construction, insulators, insulator-pins, and the like, and the conditions of operation at different voltages and under different climatic conditions; to investigate methods of testing insulators, and to indicate the method or methods which in its judgment are superior. Also to ascertain the methods employed for voltage regulation, the conditions attendant upon the switching of high-tension circuits, and to collect data respecting lightning and static disturbances and the use of grounded protective wires."

The Transmission Committee, appointed in accordance with this resolution, decided to adopt two methods of procedure. One of these was to send out printed lists of questions, relative to high-tension transmission, to the various transmission plants in the United States, with a request that answers to the questions be filled in and the lists returned.

The other was that of instituting discussions on chosen topics which would bring forth from the engineers taking part in these discussions information in regard to the work in question, which could not otherwise be obtained. These discussions took place on regular meeting evenings of the Institute, the particular meeting for which they were arranged being directly under the auspices of the Transmission Committee.

Previous to the discussion on each of the several subjects chosen for the evening, there was read an "introduction" prepared by

some member of the Institute prominent in transmission work. These "introductions" were not intended to be formal or complete "papers," but merely to serve as a basis or frame-work for discussion on the subjects with which they dealt. As it was desired that as many as possible of the members of the Institute should take part in these discussions, the "introductions" were sent out sufficiently ahead of the meeting, so that those who were not able to be present could take part in the discussion by sending in a written "contribution."

In the matter of the following pages is comprised the work accomplished by the Transmission Committee along the lines laid down above. It includes the "introductions," with the discussions which took place upon them, and the results obtained from the lists of questions sent out.

The matter is here collected in book-form by special permission of the Institute, and as it here appears has been taken directly from the Transactions of the Institute, with such minor changes as were necessary for co-ordinating the different parts.

As the work of the Transmission Committee brought out much valuable information, which is available only by searching through the pages of the Institute Transactions, it is believed that the collection of this information, in compact and convenient form for reference, will constitute a valuable addition to engineering literature.

CONTENTS.

A paper read at the 174th Meeting of the American Institute of Electrical Engineers, New York, March 27, 1903.

MECHANICAL SPECIFICATIONS OF A PROPOSED STANDARD INSULATOR PIN.

BY RALPH D. MERSHON.

A mathematical consideration of the fibre stresses in wooden insulator pins and a recommendation as regards standard dimensions and methods of construction.

At present no general standard exists in the matter of Insulator Pins. As a result, there is often confusion and dissatisfaction in ordering and obtaining pins. This discussion of a proposed standard pin is intended to lead up to a general specification covering wooden pins, and, so far as it may, metal ones.

Theory.—The expression for the extreme fibre stress at any point of a beam of circular section fixed at one end and loaded at the other, as in Fig. 1 is

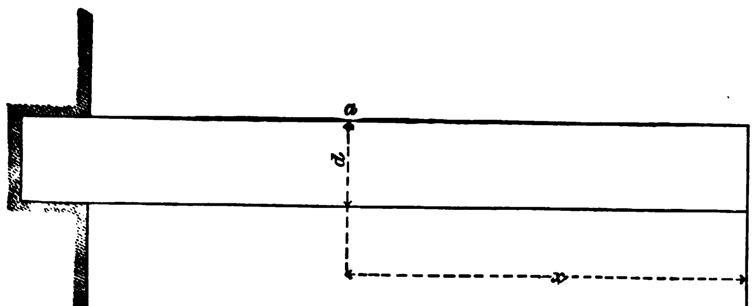


FIG. 1.

$$s = \frac{P\,x}{.0982\,d^3} \qquad (1)$$

where (assuming inches and pounds as our units) P is the pull or weight in pounds; x is the distance in inches from the point of application of P to any point a of the beam; d is the diameter in inches at the point a; s is the extreme fibre stress in pounds per square inch, *i.e.*, s is the stress on the extreme fibres at the top and bottom of the beam at the point a.

This equation shows that for a given pull P the fibre stress at any point a at a distance x from the point of application of P varies directly as x and inversely as the cube of d. It is possible, therefore, to design a beam of circular section whose diameter in passing from the point of application of P to the point of support shall vary in such a way that s will have the same value all the way along the beam. Such a beam will be of uniform strength throughout its length. The value which, in such a beam, d must have at any point distant x from the outer end may be found by assuming s and P constant in Equation (1) and solving for d in terms of x. This gives

$$d = \left(\frac{P}{.0982\,s}\right)^{\frac{1}{3}} x^{\frac{1}{3}} = K\,x^{\frac{1}{3}} \qquad (2)$$

where K is a constant whose value must be determined from the extreme fibre stress allowable with a given pull P. Equation (2) shows that in order to have the beam of uniform strength throughout its length, its diameter must vary as the cube root of the distance from the point of application of its load.

An insulator pin is the case of a beam of circular section fixed at one end and with a load (any side pull which may come upon it) applied at or near the other end. There is no object in having an insulator pin any stronger at any one point than at another. It should, therefore, in its capacity as a beam, be tapered as nearly as practicable in such a way that s will be constant throughout; that is, so that equation (2) will apply to it.

The point where pins usually break, their weakest point, is just at the cross-arm. The wooden pin most generally in use is one having a diameter of about $1\frac{1}{2}$ inches in the cross-arm and a length such that the wire is from 5 to 6 inches from the cross-arm. Let us obtain the value of K in (2) on the assumption of $d = 1\frac{1}{2}''$ and $x = 5''$. This gives the value of K as .877, so that, substituting, (2) becomes

$$d = 877\,x^{\frac{1}{3}} \qquad (3)$$

From (3) we may find the diameter required at any point in any length of pin, the pin to be of uniform strength throughout. Substituting various value of x we have the following:

x (inches)	d (inches)
1	.877
2	1.106
3	1.263
4	1.395
5	1.5
6	1.592
7	1.678
8	1.754
9	1.825
10	1.888
11	1.95
13	2.06
15	2.17
17	2.25
19	2.34
21	2.42

This table shows that for a pin having upon it a pull one inch above the cross arm, the diameter at the cross-arm must be .877 inches; that one having a pull upon it 10 inches above the cross-arm must have a diameter at the cross-arm of 1.88 inches, etc.

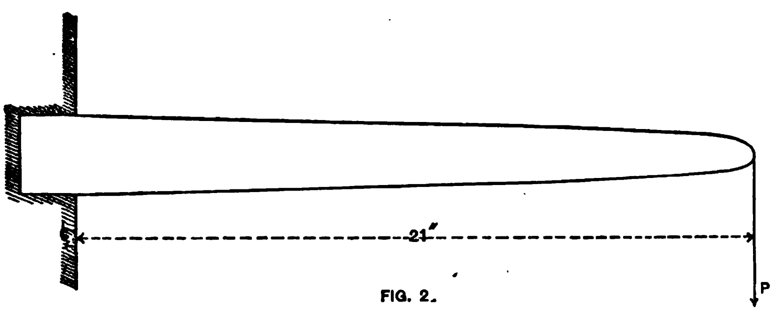


FIG. 2.

Fig. 2 is a sketch of such a theoretieal pin drawn by platting the above values to a scale one-quarter of full size. Fig. 2 represents all sizes of pins up to and including one the pull upon which is applied 21 inches above the cross-arm. That is, if we want a theoretical 6 inch pin we must cut 6 inches off the end of Fig. 2 and use that; for a 10 inch pin we must cut off 10 inches, etc.

The practical pin must be a modification of the theoretical pin. The end must be square and a portion of the small end must be threaded. The pin must also have a shoulder just above the cross-arm. It will be noticed that, except near the end, the sides of the theoretical pin are practically straight. It will suffice, therefore, if in designing a pin we fix the diameter at the lower end of the thread portion and the diameter just above the cross-arm and make the contour between these points a straight line.

Threaded End.—It is proposed to make the diameter of the small end of the pin 1 inch; the length of the threaded portion 2½ inches; and the diameter at the lower end of the threaded portion 1.25 inches,so that the threaded portion will taper from 1.25 inches to 1 inch in a length of 2½ inches. The threaded portion of the insulator should have the same dimensions and taper as that of the pin.

Shoulder.—It is proposed to make the shoulder 3/16 inch on all pins. That is, the diameter of the pin just above the cross-arm will be ⅜ inch greater than the nominal diameter of that portion of the pin in the cross-arm; it is proposed to carry this diameter ½ inch above the cross-arm before tapering the pin.

Dimensions in Cross-Arm.—It is proposed to make the diameter of that portion of the pin in the cross-arm, just below the shoulder, 1/32 inch less than the diameter of the hole in the cross-arm and at the lower end of the pin 1/16 less than the diameter of the hole in the cross-arm. It is proposed, also, to designate this portion of the pin as having a nominal diameter equal to that of the hole in the cross-arm into which the pin fits. Therefore, that portion of a pin which is to fit a 1½ inch hole in a cross-arm will have a nominal diameter of 1½ inch but will have an actual diameter just below the shoulder of 1–15/32 inch, and at the lower end of the pin of 1–7/16 inch.

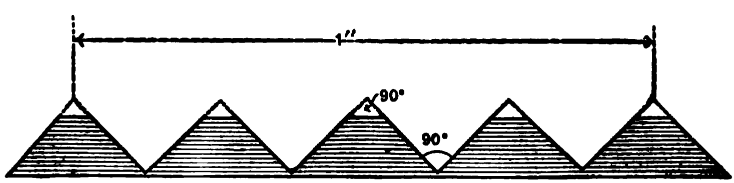


FIG. 3.

Thread.—It is proposed to use on all pins a thread having a pitch of ¼ inch or 4 threads to the inch, the form of thread to be that shown in Fig. 3 (scale three times full size). As there shown

the angle between the faces of the thread is 90° and the top of the thread is flattened by cutting off, from the form the thread would have if not flattened, one-fourth its unflattened depth. The form of the thread in the insulator should be the same as that on the pin. If this is done it will insure the bearing surface being always on the sides of the threads and never on the edges.

Designation.—It is proposed to designate that portion of the pin above the cross-arm as the " stem " of the pin. That portion in the cross-arm as the " shank " of the pin. It is proposed to designate a pin by the length of its stem, *i.e.*, a pin whose stem is 5 inches long will be designated as a " 5 " inch pin, one 6 inches long as a " 6 " inch pin, etc.

Dimensions of Standard Pins.—In accordance with the above the following table has been prepared, giving a number of sizes of pins, and their dimensions, which it is proposed to make standard. The diameter of the shank has in each case been fixed by making it approximately equal to (slightly larger than) the diameter of the theoretical pin corresponding to the length of the stem of the pin in question. The headings of the columns of the table refer to the lettering of Fig. 4.

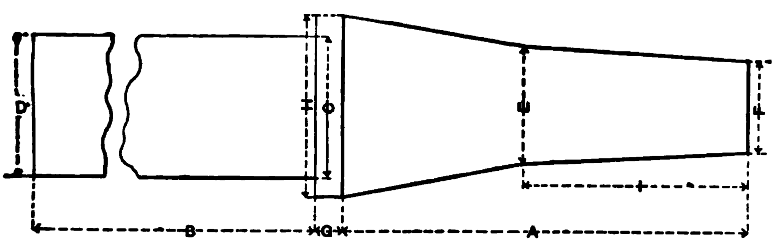


FIG. 4.

Size of Pin.	A	B	C Nominal.	C Actual.	D	E	F	G	H	I
5"	4¾"	4¼"	1½"	1 15/32"	1 7/16"	1½"	1"	½"	1⅞"	2½"
7	6¾	4½	1¾	1 23/32	1 11/16	Same for all sizes of pins.	Same for all sizes of pins.	Same for all sizes of pins.	2⅛	Same for all sizes of pins.
9	8¾	4½	1⅞	1 27/32	1 13/16				2¼	
11	10¾	4½	2	1 31/32	1 15/16				2⅜	
13	12¾	4½	2⅛	2 3/32	2 1/16				2½	
15	14¾	4¾	2¼	2 7/32	2 3/16				2⅝	
17	16¾	[illegible]¾	2⅜	2 11/32	2 5/16				2¾	
19	18¾	5¼	2½	2 15/32	2 7/16				2⅞	

A paper read at the 174th Meeting of the American Institute of Electrical Engineers, New York, March 27, 1903.

THE TESTING OF INSULATORS.

BY F. O. BLACKWELL.

A statement of the requirements for satisfactory insulators and recommendations as to apparatus and methods of carrying on insulator tests.

An electric power transmission cannot be successful unless it is able to deliver uninterrupted power.

Continuous operation, so far as the transmission line is concerned, depends largely upon the effectiveness of the insulator which is employed. Insulators must, therefore, be obtained which will not fail in service and this can only be assured by the thorough testing of each one that goes on the electric lines.

The potential that can be employed safely for the transmission of power is now limited by the pressure the insulators will bear, as transformers that are reliable and not excessive in cost can be built for twice the voltage that any line yet constructed will withstand.

As the distance over which power can be transmitted with a fixed cost of conductor varies with the potential, the length of transmission lines is to a great extent limited by the insulator.

The design of new and improved types of insulators is, therefore, most important, and these can only be developed by experiment with adequate testing facilities. In order to ascertain the value of such insulators, no method of testing can equal a practical trial under conditions of actual service. Placing new insulators on power transmission lines in commercial operation is impracticable in most cases and should only be permitted after they have successfully withstood tests to demonstrate their

ability to stand operating conditions. These tests should duplicate as nearly as possible the electrical and mechanical strains set up in the insulators under the most severe conditions that would ever be met with on a transmission line.

There are certain facts which must be considered if correct deductions are to be made from insulator tests. For instance, we cannot test each insulator with a given number of volts continuously as it would be in service. As is well known, all insulating materials are most apt to break down on long applied electric stress. The prepared cloth wrappings used on the windings of electrical machinery will stand instantaneously two or three times the potential that they will carry continuously. Glass and porcelain are not affected by time to the same extent as organic materials, but we know that both kinds of insulators have been punctured by long continued applications of lower pressures than those which they have withstood in tests of short duration.

The shape of the potential wave also has a pronounced effect in breaking down insulation. A wave may be either flat topped or peaked, so that the maximum instantaneous potential is much less or greater than that of a sine wave of the same square root of the mean square potential. We might have for the same potential as read by the voltmeter, maximum instantaneous potentials which differ as much as two to one.

In air, the maximum point of the wave determines the distance which the current will jump. Different generators or even the same generator under different conditions of load will show widely varying arcing distances for the same potential.

Insulating materials being more affected by time than air, show in their ability to resist puncture that the average potential of the wave is more important than the maximum.

It is not safe to assume the potential either by the voltmeter or air gap as the true potential for determining the insulating value, as it is somewhere between the two. Moisture in the atmosphere also effects the arcing distance. In steam, a given potential will jump twice as far and in a fog 25 per cent. farther than under ordinary conditions. Of course, if the altitude is high and the air more rarified, the arc will also jump a greater distance.

I would like to call attention to the characteristics of the apparatus required for testing insulators.

The alternators generally used for long-distance transmission plants give very nearly a sine wave and therefore the testing generator should be one which will give a sine wave under all

conditions. It is not sufficient to do so at full potential and no load, as tests are made with all degrees of excitation and with both leading and lagging currents.

The armature reaction should be as small as possible, which means that the generator should be much larger than would ordinarily be thought necessary. It is also desirable to have a high reluctance in the magnetic circuit to secure stability when running with weak fields and permit of control with a reasonable amount of field resistance.

There should be but one transformer used to step up to the highest potential required and its reactance should be as low as possible. A number of transformers in series is particularly bad, as it gives poor regulation and leads to great uncertainty as to the actual potential to which an insulator is being subjected.

I have known testing sets with transformers in series and a generator of poor regulation to vary widely in the relation of the generator volts and the length of the spark gap due to change of wave form with different magnetic saturations of the apparatus and different numbers of insulators and consequently various capacities on the testing circuit. The only certain way to determine the real potential is to have a step-down instrument transformer on the high potential circuit.

Assuming that insulators are to be passed upon for a specific transmission plant, they should first be inspected to see that they are free from cracks, bubbles or pits that will impair their strength or in which moisture can lodge. If of porcelain, the glaze should cover all the outer surfaces. The glaze is of no insulating value in itself, but dirt sticks to unglazed surfaces.

Experience has shown that porcelain insulators which are not absolutely non-absorbent are worthless. The best porcelain shows a polished fracture like glass. If there is any doubt about the quality of the porcelain in this respect, it should be broken into small pieces, kept in a hot dry place for some time, weighed, and immersed in water for a day. When taken out of the water the weight should be the same as at first. A puncture test should be made by setting the insulator in a cup of salt water, filling the pin-hole also with water and slowly increasing the potential between the top and bottom until the desired test potential is reached or the insulator either punctures or arcs over the surface.

If an insulator is built up of several parts, each part should be able to withstand a pressure greater than it will have to sustain

when the complete insulator is tested. If it is to be tested for 100,000 volts and is made in two parts, each part might, for instance, be tested with 70,000 volts. The object of this is to have the weak parts rejected before they are assembled. A fair puncture test for an insulator is twice the potential for which it is to be employed, applied between the head and the interior for one minute. For example, the insulators for a 50,000 volt line should each stand 100,000 volts. As the potential from any wire to ground on a 5000 volt three-phase system would only be about 30,000 volts, a 100,000 volt test gives a factor of safety of nearly three and one-half to one. If one branch were grounded, as sometimes occurs in practice, the factor of safety would be but two to one. A one-minute test is not so severe as a continuous application of an equal potential, but insulators that have passed this test stand up well in service.

New types of insulators should be mounted on iron pins and tested both wet and dry, to determine the potentials which will arc over them. The dry test is of little value, as the potential at which the arc jumps from the head to the pin can be predetermined by measuring the shortest distance between them and referring to a curve of arcing distances in air. In a wet arcing test, a stream of water from a sprinkler-nozzle under a pressure of at least 50 pounds to the inch should be played on the insulator at an angle of say 30 degrees from the horizontal. This will be similar to the condition which exists in a rain and wind storm. The insulator should not arc over from the wire to the pin at less than the potential which will exist in service between any two conductors.

In no case should wooden pins be relied on for insulation, as their value is only temporary. All wooden pins in time become dirty, absorb moisture and eventually burn off unless the insulator is good enough to be used with an iron pin. If an insulator is going to fail, it is better to have it do so at the start and not interrupt the service bv breaking down perhaps years afterwards.

In addition to the electrical tests, it is well (if the insulator is of a type that seems to require it), to try samples for mechanical strength. When mounted on pins the insulator should stand a side strain of at least ten times the pressure exerted by the air on the conductor with a wind velocity of, say, 100 miles an hour.

It should also be able to slip the conductor through the tie-wire should the former break.

These tests are particularly desirable with built-up insulators in order to be certain that the parts will not separate. With such insulators, it would also be well to test them in tension along the axis of the pin, as in transmission lines crossing depressions such an upward pull is not infrequently exerted on the insulator.

The above notes and suggestions are the result of the writer's tests of insulators, and observations of high potential lines. There are many members of the Institute whose experience has been wider and who have doubtless given the matter much thought.

It is the purpose of this paper only to touch briefly upon an important subject in order to open a discussion which it is hoped will bring out much valuable information.

A paper read at the 174th Meeting of the American Institute of Electrical Engineers, New York, March 27, 1903.

TRANSPOSITION AND RELATIVE LOCATION OF POWER AND TELEPHONE WIRES.

BY P. M. LINCOLN.

A consideration of the causes of electrical disturbances in telephone lines which parallel high-tension lines, and of means for reducing these disturbances.

(1) The extraordinary sensitiveness of the telephone receiver makes this instrument peculiarly susceptible to electrical disturbances. One authority states that the energy used in a sixteen candle power incandescent lamp is sufficient to produce an audible sound in thirty billion receivers. The methods, therefore of shielding telephone wires from the inductive effects of neighboring wires become important. Particularly is this true in the case of a telephone line paralleling a high-tension transmission line, where the inductive disturbances are apt to be large, and uninterrupted service on the telephone line important.

(2) The remarks and discussion in this " Introduction to Discussion " apply particularly to telephone lines paralleling high-tension lines, but comments hereon need not be restricted to such cases.

(3) There are three ways in which disturbing current in telephone circuits may be caused by the high-tension circuit.

(1) Electromagnetic induction.
(2) Electrostatic induction.
(3) Leakage.

It is the first two causes of disturbances which will claim particular attention in the following discussion.

(4) Electromagnetic induction may be briefly described as a transformer action. In Fig. 1 let *a*. *b* and *c* be the conductors of a three-phase line, and *m* and *n* the two wires of a paralleling telephone circuit. *a* and *b* may then be regarded as the primary and *m* and *n* as the secondary of a transformer. The e.m.f. in circuit *mn* will depend, among other things, upon the amount and frequency of the current in the inducing circuit. By transposing *m* and *n* in the well-known manner, the e.m.f.'s set up in one part of the telephone circuit will be neutralized by equal and opposite e.m.f.'s set up in other parts. Thus, the electromagnetic effects between *m* and *n* may be entirely neutralized by trans-

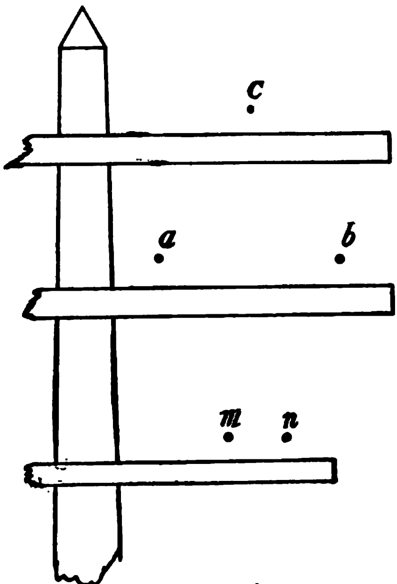


Fig. 1

posing the telephone wires only, regardless of whether the transmission wires are transposed or not. It may be well to note, however, that while the e.m.f. *between* the two telephone wires may be reduced to zero by properly transposing the telephone wires only, the e.m.f. between the two telephone conductors considered as one side of a circuit and the earth as the other, can be reduced to zero only by transposing the power wires. This point is of little importance, however, as any electromagnetic e.m.f. between the telephone wires and ground is entirely overshadowed by the electrostatic which will be considered later.

(5) Electrostatic effects will also take place in *m*, *n*, due to transmission circuit *a*, *b*, *c*. If conductor *a* has a minus charge

for instance, it will induce a certain plus charge on *m* and a smaller plus charge on *n*, on account of *n's* greater distance from *a*. If now the minus charge be removed from *a*, current will flow from *m* to *n*, proportional to the difference in the amounts of these charges. The electrostatic influence of *b*, being oppoite *a* in sign, will reinforce the action of *a*. Transposition of the telephone wires will have the effect of neutralizing this tendency of setting up electrostatic currents between *m* and *n*. It is important to note that a system of transpositions designed to correct electromagnetic induction between the wires will also be correct for electrostatic induction.

(6) Considering the comparative electromagnetic and electrostatic disturbances in a section of untransposed telephone line, it may be interesting to observe that the first is in the nature of a constant potential effect and the second of a constant current effect. It is evident that induced electromagnetic e.m.f. is constant as long as the inducing current is constant. As for the electrostatic effect, it is evident that the amounts of the induced charges on *m* and *n*, and therefore the electrostatically induced current between them, will not become appreciably reduced until the current flowing between *m* and *n* makes a difference of potential between them appreciable, compared with the inducing difference of potential. With telephone receivers of varying resistance, therefore, the ampere-turns in the receiver due to electromagnetic induction are practically constant, while those due to electrostatic induction increase with number of turns and therefore the resistance of receiver. The electrostatic and electromagnetic effect become roughly equal with an arrangement shown in Fig. 1, when *a*, *b*, *c* is a line carrying 50 amperes at 20,000 volts, and the telephone circuit contains a total resistance of 1,000 ohms, including receivers.

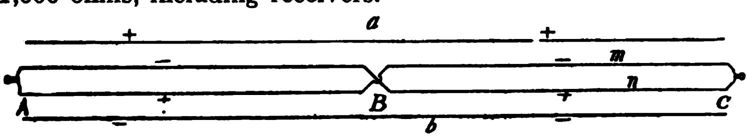


Fig.2

(7) The bridged telephone has almost universally taken the place of the series instrument for all telephone work. The series telephone is particularly objectionable for use on a circuit in which static induction takes place to any great extent. The reason for this is seen by an inspection of Fig. 2. The telephone

wire m has between A and B a plus charge induced and between B and C a minus charge. There is, therefore, at the transposition point B a flow of current from one section of m to the other. If now a series telephone be placed in series with m at B, it not only gets the benefit of this charging current between the two sections of m, but it also creates a difference of potential and, therefore, disturbing currents in telephones at A and C as well.

(8) Although a proper system of transposition will prevent the establishment of an induced e.m.f. *between* the two telephone wires, it does not necessarily prevent the two wires from assuming a potential which differs from that of the earth. In a properly transposed system, each telephone wire is the same average distance from each power wire. The potential, therefore, which the telephone system tends to assume from the static induction of the power wires is that of the neutral point of the power system. By neutral point is meant that point between which and each of the power wires the average e.m.f. is the same. Under normal conditions this neutral point is at ground potential. If, however, leakage takes place from one of the power conductors to ground, this neutral point will differ in potential from the ground and the amount of this difference becomes greater as the resistance of the leak becomes less. In a three-phase system, when the resistance of this leak becomes zero, the maximum difference of potential between the neutral point and ground occurs, and is 58 per cent. of the power circuit voltage. In a 20,000 volt system, for instance, there may exist a potiential of nearly 12 000 volts between the neutral point and ground. When the neutral point of the power line differs in potential from the ground, an electrostatic difference of potential tends to exist between the telephone wires and earth, and will exist if the insulation of the telephone circuit is perfect.

(9) The amount of this electrostatic potential between the telephone circuit and the earth will depend upon the relative capacities between power and telephone lines on one hand and between telephone line and earth on the other. The power and telephone lines may be considered as opposite plates of one condenser and the telephone line and ground as opposite plates of another condenser. These two condensers being in series, they will distribute the total e.m.f. in inverse ratio to their capacities. With usual construction, the capacity between telephone line and ground will not be less than that between telephone and power wires, so that the potential of the telephone wires above ground

will be equal to at least one-half the potential of the power line neutral point above ground. A grounded power line may thus cause a potential between the telephone wires and ground which will reach well into thousands of volts and even a bad insulator may cause such an e.m.f. measured by hunderds of volts. In this connection it is significant to note that in the great majority of cases the telephones become inoperative when a ground occurs on the power lines. Is it any wonder? How many telephone lines are built to stand up under a strain of even 1,000 volts, let alone 5,000 or 10,000 volts to ground? It is hardly necessary to point out the path of the disturbing currents. The first voltage strain comes not between telephone wires, but between the two wires and ground. A break down of its insulation, either partial or complete, occurs at some point, and the wire to which the break occurs discharges to ground either partially or completely and the other wire must discharge *through the telephones* to ground.

(10) The points, therefore, which deserve careful consideration in the installation and operation of a telephone line when it is to be operated in proximity to a high-tension transmission line are the following:

(1) Insulation.
(2) Transpositions.
(3) Use of bridge telephones instead of series telephones.
(4) Making static capacity of telephone wires to ground as great as possible, and capacity to power wires as small as possible.

(1) *Insulation.*

(11) Insulation is put first as being the point of first importance. A ground on the transmission line is going to cause either volts or trouble on the telephone line. There is no reason why the telephone wires will not transmit speech properly, even if it does differ in potential from the ground. But to obtain this result, disturbing currents from the line to earth must be prevented by perfect insulation. When it is realized that the potential between the telephone line and ground may be as high as 30 per cent. of the potential between power wires, the importance of insulation is better understood. By insulation, too, is meant the insulation throughout the entire line. There is little use in providing glass insulators for pole supports capable of standing a voltage of 15,000 or 20,000 and then, inside buildings, attaching the telephone wires directly to woodwork which may be damp, or

to an instrument mounted on a damp brick wall. Above all, there is no use in putting up a line which may be able to stand a test of 15,000 or 20,000 volts, and then attach to this same line a lightning arrester which will break down at 300 volts, as the standard telephone lightning arrester is expected to do.

(12) When providing high tension insulation for the telephone line, the insulation of the man using it should not be forgotten. This insulation of the telephone user is advisable, not only to protect him from the induced voltage but also to protect him in case of a cross with the power line. The induced voltage is not so dangerous as its amount would indicate because the current is limited to that of a condenser consisting of power line as one plate and the telephone line as the other. It may be noted that the telephone insulation is subjected to high strains only when the power line is grounded or heavily unbalanced statically. This is just the time, however, that uninterrupted service of the telephone line is apt to be of the utmost importance.

(2) *Transpositions.*

(13) The necessity of transposing the telephone line is almost so apparent as not to need comment. Otherwise continuous disturbances will exist, due both to electromagnetic and electrostatic effects. So far as the telephone line is concerned, transposition of the power wires is not so important. An untransposed power line cannot induce either electrostatic or electromagnetic effects between two transposed telephone wires, but only between these two wires and ground. The amount the statically balanced untransposed power line can elevate the telephone wires above the ground potential is small compared to the effect of the power line when statically unbalanced, whether transposed or untransposed. If the telephone line is insulated to meet the worst conditions, it will be ample to meet the normal condition of an untransposed power line.

(3) *Use of Bridge Instead of Series Telephones.*

(14) This point is one which need only be mentioned. The advantages of the bridged over the series telephone are so well known that the reason before mentioned for using a bridged instead of a series instrument is simply throwing another shovelful of earth on the grave of the series instrument.

(4) *Making Capacity of Telephone Wires to Earth as Great as Possible, and Telephone Wires to Power Wires as Small as Possible.*

(15) In Montana there is a line in operation at 50,000 volts.

Other lines are projected as high as 60,000 to 80,000 volts, and there is a possibility of going higher. When one realizes that with the usual construction as shown in Fig. 1, there may be in such cases an elevation in the potential of the telephone wires of 20,000 to 25,000 volts above ground he begins to cast about for some method of reducing this potential. The total voltage between the neutral point of the power wires and ground may be considered as taken up across two condensers, one consisting of the power and telephone wires, and the other the telephone wires and earth. To decrease the possible potential of the telephone wires to ground, therefore, one must either decrease the capacity of the power wire—telephone wire condenser, or increase the capacity of the telephone wire—earth condenser, or both. This may be accomplished by increasing the distance between power and telephone wires, and decreasing the distance between telephone wires and earth. If the same supporting structure be used, there is a limit to which this can be carried, at which the possible voltage between telephone wires and earth may be still prohibitive. The capacity of the telephone wire-earth condenser, may be still further increased by bringing the earth to the telephone wires, instead of the telephone wires to earth. That is, one or more ground wires may be run in close proximity to the telephone wires, thereby increasing the capacity of the telephone wire-earth condenser, to almost any desired limit. By this means the possible potential between telephone wires and earth may be brought within limits where it may be taken care of with safety.

(16) In conclusion, the writer asks for the freest comments on the foregoing remarks, particularly from those who have had experience in operating a telephone line paralleling high-tension wires. If such can agree with the writer in his remarks, he will be pleased to know it. If they cannot agree, he will be still more pleased to find out wherein he is wrong.

A paper read at the 174th Meeting of the American Institute of Electrical Engineers, New York, March 27th, 1903.

BURNING OF WOODEN PINS ON HIGH-TENSION TRANSMISSION LINES.

BY C. C. CHESNEY.

Facts concerning a number of examples of the burning of wooden insulators pins and a recommendation as to the use of iron pins.

In this country it has been almost the uniform practice in high-tension pole line construction to use wooden pins. The reason for their use has been the belief that because they were made of wood they strengthened the entire insulation of the pole line system, and were in consequence additional safeguards. These pins have generally been made of locust, oak or eucaliptus; and in order that the insulation might not deteriorate from the action of the weather, they have usually been treated carefully with hot asphaltum, paraffine or linseed oil. The temperature and character of the treating liquid have depended more or less upon the whim of the constructing or designing engineer. Although there has been no uniform method followed and although the materials used in the treatment have differed greatly, the results have been universally the same. Wood pins when used with glass or well vitrified porcelain insulators, have given very good service on potentials as high as 25,000 or 30,000 volts. There have been no unusual pin troubles at these voltages which could not readily be explained by porous or cracked insulators or by some peculiar climatic conditions. In my opinion, the success secured in the operation of the great majority of these lines is due to good insulation of the insulator, and the insulation of the pin has in reality contributed very little to that success. For 40,000 volts and for higher potentials, the insulators offered by all manufacturers do not have the same factors of safety as

the insulators for lower voltages offered by the same manufacturers. The difference is not so much in the thickness or in the quality of the glass or porcelain used; it is more particularly in the general shape of the insulator and in the dimensions of the insulating surfaces and petticoats. For this reason, even under severe local surroundings, the 10,000, 15,000, 20,000 or 30,000 volt insulators have shown very little surface leakage and in consequence there has been comparatively little pin burning at these voltages. It is true that in localities of salt storms, of

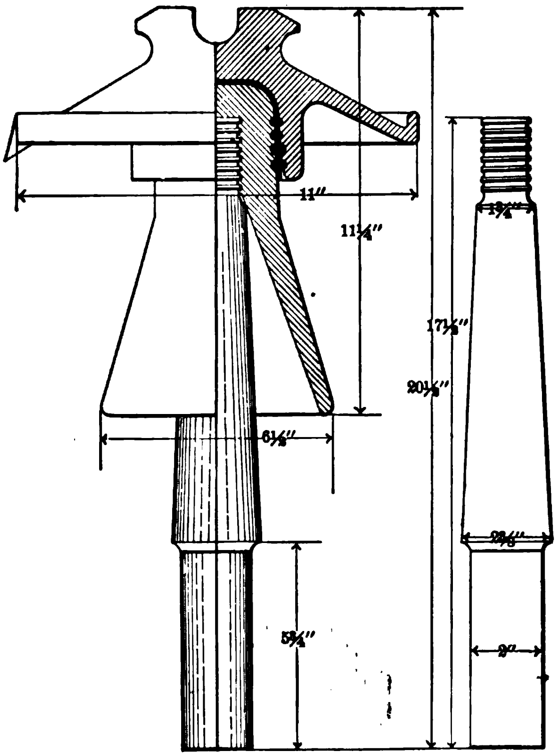


FIG. 1.

heavy sea fogs or chemical factories, there has been more or less pin burning without regard to the type of insulator used, or to the potential of the system. The writer has been informed that a certain plant using only 440 volts has at times great trouble from the burning of pins, although 10,000 volt insulators are used. This trouble is due entirely to the deposit on the insulators from a neighboring chemical factory, and as might be expected their period of no-burning is during the rainy season. These instances

however, are rare, and when the cause is apparent, the remedy is usually at hand. The pin burning on 40,000 and 50,000 volt lines is somewhat different. Eliminating all causes due to broken or defective insulators, the actual flow of current over the surfaces and through the body of the pin is probably very small. On the lines from which the writer has secured burned pins two used 11-inch Locke insulators, as shown in Figs. 1 and 2; the third used the Redlands type, Fig. 3. The first two lines were operated at a potential between 45,000 and 50,000 volts, and the

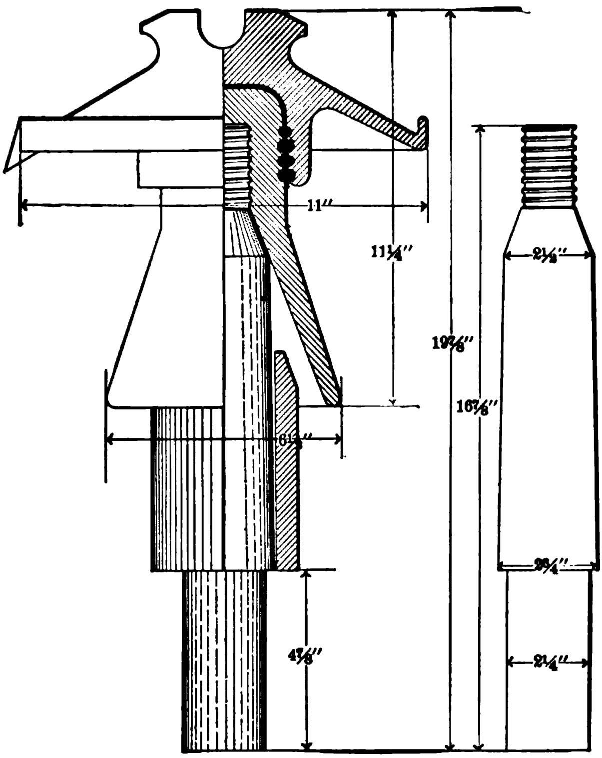


Fig. 2.

third at about 33,000 volts. The pins shown were taken from perfect insulators and in some cases the insulators were immediately put back on the line. Pins shown in Figs. 1 and 2 were made of eucaliptus and boiled in linseed oil. The line using pin shown in Fig. 2 also used a porcelain sleeve covering the base of the pin. Fig. 3 shows the well-known Locke iron-pin with porcelain base and oak thread. Fig. 4 and Fig. 5 show three pins all of the type shown in Fig. 1. These pins were taken from the same

pole and occupied the relative positions as shown in the cuts. The burned sides stood towards the damp winds from the ocean. Fig. 6 shows a burned pin of the type shown in Fig. 2. Fig. 7 is the Locke iron-pin with porcelain base (Fig. 3) taken from a 33,000 volt line. The striking feature is the burning of the wooden thread to the iron pin. The writer has been informed by the general superintendent of this plant that every pin that has been examined on this line is burned in exactly the same way, yet

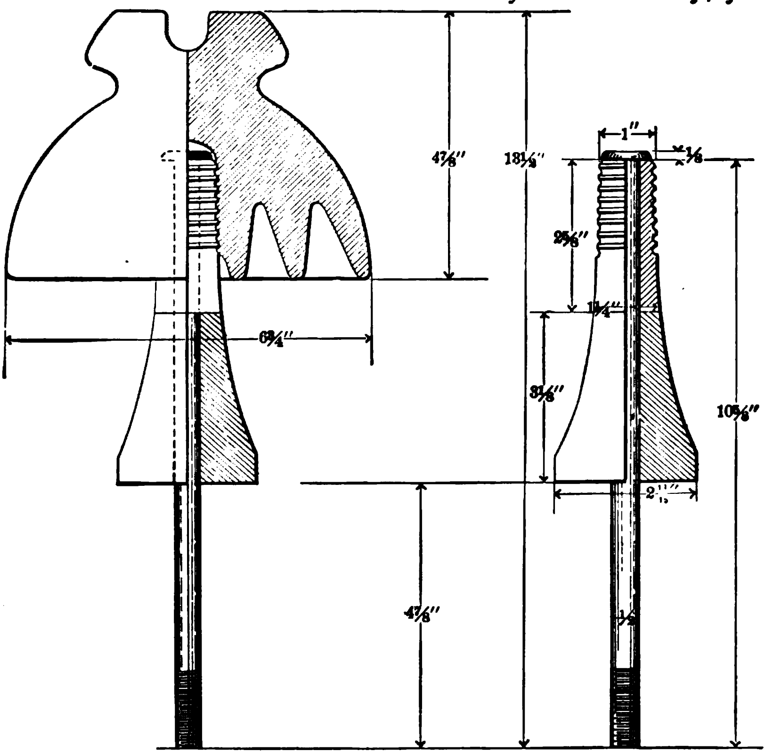


Fig. 3.

there has been comparatively few punctured insulators and no cross-arms burned from the current leaking over the surface of the insulators. Fig. 8 shows the pin taken from the same 50,000 volt line as those shown in Fig. 4. This pin is shown sawed in sections in Fig. 9. The noticeable feature is that the burned section is entirely in the upper part of the pin about 1¾" below the thread. The outside surface and the centre of the pin below this point shows no charring. It would appear that at least in this instance the burned section was the point of highest resistance of the pin, and that the lower part of the pin was a good

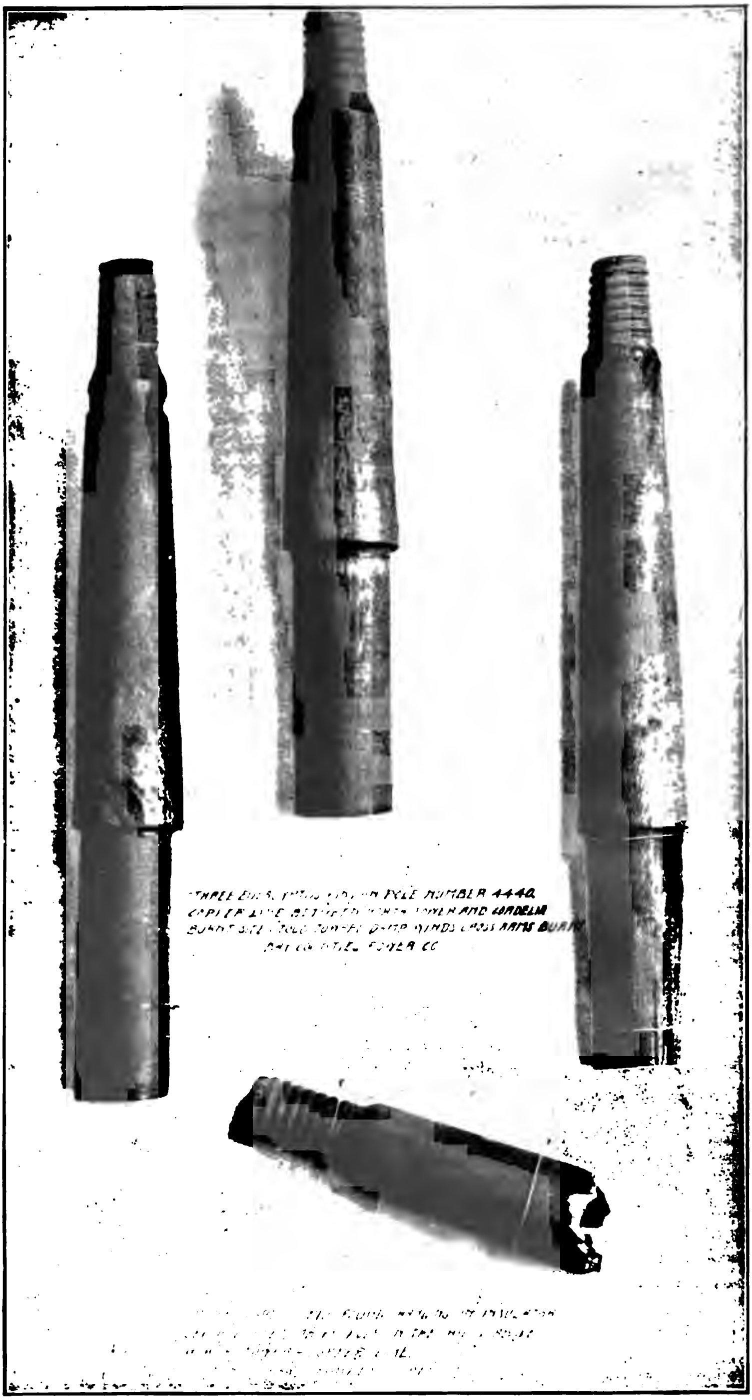


Fig. 5.

FIG. 4.

Fig 8

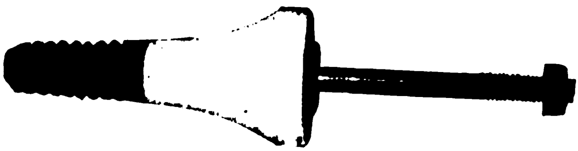


Fig.7

Fig.6

Fig 10.

Fig 9.

enough conductor to permit the small current which leaked over the surface of the insulator to flow without any special generation of heat in that section of the pin. The reduced insulation of the pin and insulator was no doubt due to the dust and fog. The upper portion of the pin, being better protected by the insulator from fog and dust, had in consequence higher surface resistance. The dark spot shown on the right hand edges of the lower section of Fig. 9 is the sap section of the wood and has been discolored by the linseed oil boiling which the pin originally had. This section has been in no way affected by the current. In Fig. 9 is illustrated a peculiar action which is occasionally found on high tension transmission lines, and which, for a better name, has been called "digesting the thread of the pin." The thread of the pin softens while in service and may be rubbed off with the fingers. This soft wood has a sour taste and resembles digested wood pulp. This action is not necessarily accompanied by the burning of any portion of the pin.

The evidence here presented, while not conclusive, still points to the advisability of using iron pins with modern insulators properly chosen for the line potential.

DISCUSSION.

PRESIDENT SCOTT:—The subject of the meeting this evening is Power Transmission on High-Tension Lines.

There are a number of different subjects to be presented; these have been prepared by the members of the Transmission Committee as introductions to discussions,*not as complete, formal and exhaustive papers in themselves, but written with the intent of calling attention to and introducing a number of points on the several subjects which would lead to contributions from others. Mr. Mershon and I think that the best method of conducting the meeting this evening would be to take up each subject in turn and to devote a specified time to it, so that some attention could be given to all. The gentlemen having the subjects in charge will have a certain amount of time at their disposal. They can present the written material first and then the subject will be open to general discussion for the remainder of the half hour which will be allotted to each of the subjects. The first topic is "Mechanical Specifications for a Proposed Standard Insulator Pin," by Ralph D. Mershon.

MR. RALPH D. MERSHON:—Before the discussion is begun; I wish to state that my object in writing this introduction was to get a discussion sufficiently full to form the basis of recommendation to the Standardization Committee.

There are a number of written contributions which I shall read. The first is from Mr. M. H. Gerry, Jr., of the Missouri River Power Co.

MR. M. H. GERRY, JR.—It is too early in the development of high-tension transmission to attempt to make standard the details of construction. Such action at this time by the INSTITUTE would

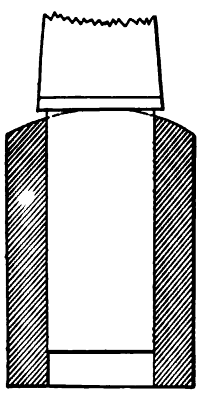


FIG. 1

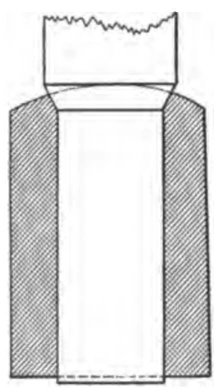


FIG. 2

result not only in failure, but in a tendency to prevent advancement in this line. However, a full discussion by the membership cannot fail to be of great advantage and profit.

Mr. Mershon has suggested the adoption as standard of certain forms of wooden pins, the designs of which conform to common

* See preceding pages.

construction. Most engineers of experience, however, would be in favor of a diameter greater than one inch at the top of the pin, and a greater length of thread than two and one-half inches. Wooden threads most frequently fail by shearing, and the strength in this particular is greatly increased by a larger diameter of pin, and a greater length of thread. The longer thread is

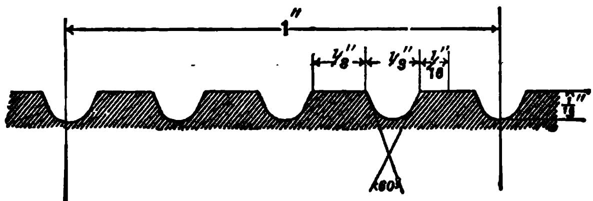


FIG.3

an advantage also in preventing the insulator from tipping out of line, when the fitting is loose between the thread of the pin and that of the insulator.

The shoulder of the pin, as suggested by Mr. Mershon, has certain disadvantages for heavy construction. On account of the rounding off of the top of the cross-arm, this form of shoulder

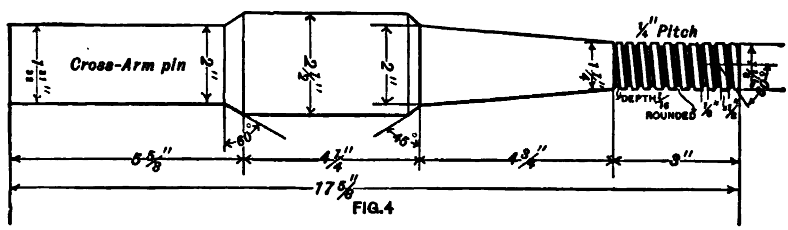


FIG.4

does not bear well, as shown in sketch, Fig. No. 1, and the sharp corner at the point of greatest strain, introduces an element of weakness. In Fig. No. 2, a form of shoulder is shown which has been used by the writer with considerable success. This shoulder tapers at an angle of 60°, and fits into a counter-bore in the top of the cross-arm. With this design the pins may be driven to a

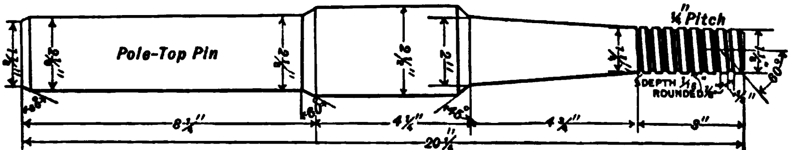


FIG.5

firm bearing at the top of the cross-arm, which has the effect of steadying them and increasing the strength of the construction at this point.

In lieu of the form of thread proposed by Mr Mershon, the writer suggests that shown by sketch, Fig. No 3. In this design

the square top of the thread is as wide as the groove, resulting in increased area of wood to withstand shearing strains. The threads of the insulators are always stronger than those of the pins, and for this reason the form of thread as proposed has considerable advantage. This form of thread may also be easily cut, in either seasoned or unseasoned wood, and the depth not being so great the pin is stronger at the bottom of the thread.

Fig. 6

Figs. No. 4 and No. 5 are drawings of the high-tension pins now used by the Missouri River Power Company. They show the form of the thread and of the shoulder as described above, and also give the general dimensions of the pins. The upper shoulder as shown by the drawings is for the support of a glass sleeve, which is used to protect the pin from the weather. Fig. No. 6 is from a photograph of the 50,000 volt line insulator assembled on one of the pins.

MR. MERSHON:—The next written contribution is by Mr. William R. C. Corson, Electrical Engineer, of Hartford, Conn.

MR. WILLIAM R. C. CORSON:—I believe I am only concurring with the general feeling in expressing my pleasure that our Committee on High-Tension Transmission has seen fit to commence its work by an effort to standardize an essential element of construction, and in hoping that this line of effort may be continued and result in recognized and approved standards for all other items capable of a general determination.

Mr. Mershon's method of developing the table of dimensions of the proposed pin is so rational that criticism of it is difficult. Briefly stated, of course, this method assumes the pin in general use as a basis, and mathematically determines the diameters of pins of differing length, which shall be capable of sustaining the same tension at their extremity as will this pin. In other words, the safe load that may be applied at the top of the proposed pins is of constant value in all. This value is not discussed in the "Introduction," and feeling that its determination would be of interest to me, and might prove of value, I have made a series of tests in a Sellers' machine to ascertain the value of s in equation (1,) for the ordinary locust pins, under the actual conditions of support suggested.

Six standard locust wood pins were selected at random from a supply at hand. The larger diameter of the shank varied from 1 7/16 inches to 1½ inches, while the smaller diameter was uniformly 1 11/32 inches. These were supported in a 1½ inch hole in a hard wood block, and the measured tension applied about 4½ inches from the block, the exact distance of the point of application being measured.

The load was very gradually applied in increments of a few pounds, and the amount noted when the first separation of the fibre appeared. Most of the specimens showed distress at from 700 to 750 lbs., with maximum strength of about 10 per cent. above this. One specimen, however, showed a crack at 600 lbs., and an ultimate strength of 1083 lbs. The average value of s determined from the tension at which the first fibre separation appeared was 11,130 lbs. per sq. inch, and the average value calculated from the maximum loads sustained was 13,623. The value of s, calculated for the specimen crackling at 600 lbs., was 9,280. While this is somewhat below the average due to an apparent defect in the wood, it is probably best to assume that for a maximum load, s should not be greater than 9,000. Assuming this value, the maximum load that may be applied to the proposed pins at a distance from the cross-arm equal to the designation of size, would be as follows:

Size of Pin.	Value of P.	Size of Pin.	Value of P.
5 in.	557	13 in.	621
7 "	639	15 "	694
9 "	615	17 "	670
11 "	610	19 "	700

Of course these values of P would be identical but for the difference between the actual diameter selected and that of the theoretical pin. The average value is 636 lbs., which may be considered the maximum load that the standard pins will sustain at the point designated.

Even with very generous factors of safety, it would appear that the pins suggested would prove of ample strength to withstand the side strains to which they may be subjected. For heavy work and for end poles, an insulator carrying the wire at some distance below the top of the pin would, of course, increase the strength of the construction. A table of standard insulators could perhaps with advantage be prepared so proportioned between groove and bottom of threaded bore as to maintain the stress on the pin within the allowable safe values for the various tensions applied.

I would call attention to one seeming error in the table of the dimensions of the proposed pins. In the paragraph headed " Designation," the following appears: " It is proposed to designate that portion of the pin above the cross-arm as the ' stem ' of the pin," and further, " It is proposed to designate a pin by the length of its stem." From this definition the stem of the pin would have a length equal to the sum of the dimensions A and G of the table.. For the five-inch pin shown in the table this would be 5¼ inches, and thus is not equal to the designation.

MR. MERSHON:—Another written contribution to this discussion is by Mr. C. L. Cory, of San Francisco.

MR. C. L. CORY:—The mechanical strength of insulator pins for use on long distance transmission lines has been given much consideration by electrical engineers in California during the past six years. For the most part the insulator pins in use are wood. On the 33,000 volt, 83 mile, double circuit, three-phase transmission line of the Edison Electric Co., from their Santa Ana power house to the city of Los Angeles, iron pins with porcelain sleeves are used. This transmission is the most notable system in California at the present time using insulator pins other than wood.

Eucalyptus has been found to be perhaps the best wood to use for insulator pins. After being turned up and threaded, they are usually treated with hot linseed oil. This treatment is desirable more on account of the protection which such treatment gives the pin against weather than on account of the insulating qualities of the oil or oil treatment.

It should be understood in this connection that an insulator pin should be depended upon only to support the insulator. The insulator in turn should be depended upon to provide the necessary insulation for the line wires. No pin after being in use for a few years on a pole line can maintain to any marked degree the insulating qualities originally existing, due to such oil or paraffin treatment.

The tests outlined below were made in the electrical laboratory of the University of California, for the purpose of determining

how near the pins generally in use in California conform to the proposed standard pins suggested by Mr. Mershon. In the test twenty-two pins were broken. These were not selected particularly for the test, but were taken at random from a large lot of such pins which were to be used in construction work. Of these, twelve were of the size generally in use on transmission lines where the voltage does not exceed 30,000 volts. These pins are 11½ inches long, including shank and stem, the latter being 6⅞ inches in length. The other ten pins tested were of the size used on the lines of what has been known as the Bay Counties Power Co., now the California Gas & Electric Corporation, and the Standard Electric Co. The line voltage in each of these transmission systems is from 40,000 to 60,000 volts. These pins are

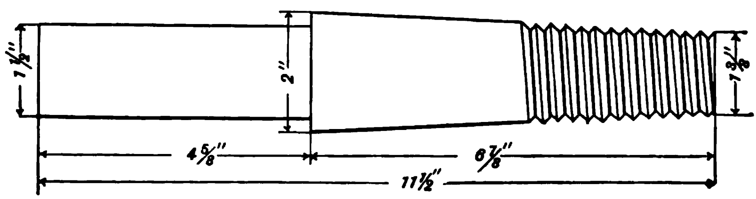


FIG. 1

15¾ inches long, including shank and stem, the latter being 10⅛ inches long. All of the dimensions of the pins tested are given in Figs. 1 and 2.

These pins do not exactly conform in size or length of stem with any of the proposed standard pins. Below, however, is given the comparative dimensions of the two samples of pins tested and the nearest sizes of the corresponding proposed pins. For sake of comparison, a 7-inch pin, as proposed, is contrasted with the 6⅞ inch tested pin, and the 11 inch proposed pin is contrasted with the 10⅛ inch tested pin. The above dimensions refer to the length of the stem of the pin, as suggested by. Mr Mershon.

COMPARISON OF PROPOSED PIN AND PINS TESTED.

	Size of Pin.	A	B	C Nominal	C Actual	D	E	F	G	H	I
Proposed Pin.	7"	7"	4¼"	1¾	1 23/32	1 11/16	1¼	1"	¼	2⅛	2⅛
Pin Tested.	6⅞	6⅞	4⅝	1½	1½	1½	1¾	1⅜	—	2"	3
Proposed Pin.	11	11	4¾	2	1 31/32	1 15/16	1¼	1"	¼	2⅜	2⅛
Pin Tested.	10⅛	10⅛	5⅜	2 1/16	2⅛	2 1/16	2⅛	1⅜	¼	2½	2⅛

In general, it will be seen that the dimensions of the proposed and tested pin agree fairly well. The most marked difference is in the diameter of the portion of the pin which is threaded to

receive the insulator. It seems evident that one inch is not a sufficient diameter for the thread of the pin for all sizes. If there is any burning of the pin just below the insulator, the inevitable result will be breaking at the bottom portion of the thread. Such a break will usually leave the pin, except the threaded portion, standing in the cross-arm, while the insulator with the threaded portion of the pin inside, will hang suspended on the line wire. This sort of break has often been observed on high-voltage transmission lines.

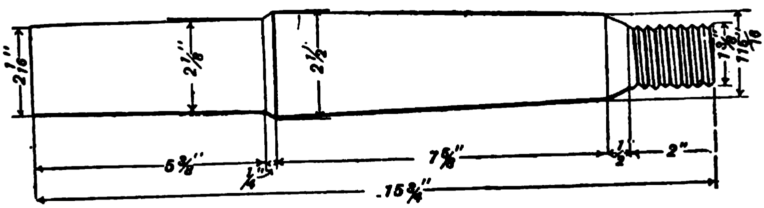


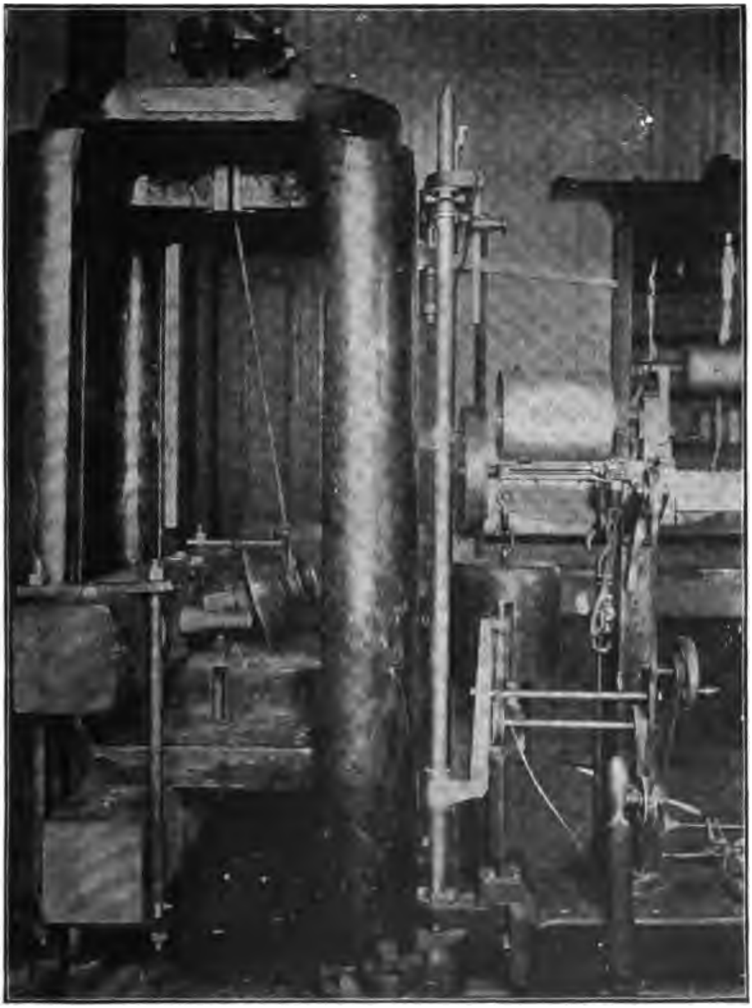
FIG. 2

The method of testing the pins is clearly shown in the accompanying photograph. It was impossible to mount the cross-arm in the testing machine so that the strain on the pin would be at right angles to its axis. The variation from a right angle, however, is small and to a certain degree conforms with the direction of the strain on the pin, due to the sag in the line wire. The "breaking load," as given in the tables below, refers to the strain in the direction of the cable, while the "real breaking load" is the component of this strain at right angles to the axis of the pin.

No.	Breaking Load.	Real Breaking Load.	No.	Breaking Load.	Real Breaking Load.
1	1010	950	1	2250	2120
2	1090	1035	2	3140	2960
3	1450	1360	3	2380	2240
4	1360	1280	4	2010	1890
5	920	865	6	2780	2620
6	1220	1150	7	2280	2140
7	1350	1270	8	1570	1475
8	940	875	9	2390	2250
9	1360	1280	10	3390	3190
10	1360	1280	Average.	2465	2310
11	750	705			
12	1060	1010			
Average.	1155	1085			

The average results, referring to the "real breaking load," of the tests of the two pins are respectively, 1085 pounds for the $6\frac{3}{4}$ inch pin and 2310 pounds for the $10\frac{1}{2}$ inch pin. The character

of break in the two pins, however, is not the same. Almost without exception, the 6¾ inch pins were broken approximately square off at the cross-arm. The larger pins, however, split in the stem, the beginning of the split being just at the bottom of the thread. An inspection of the photographs clearly shows the difference in the character of break in the two pins.



Method of Mounting Cross-Arms, Pins and Insulators in Testing Machine.

It seems from the tests that the shank is the weakest part in the 6¾ inch pins, while the stem, and particularly the upper portion of the stem, or thread, is the weakest part of the 10½ inch pins

The variation of the "real breaking load" for the different $6\frac{7}{8}$ inch pins tested is from 705 pounds minimum to 1360 pounds maximum. For the $10\frac{1}{8}$ inch pins, this variation is from 1475 pounds minimum to 3190 pounds maximum.

During the progress of the test, it was observed that the "allowable breaking load" was least when the pin was turned in the cross-arm, so that the strain was across the grain of the pin, while the greatest allowable "breaking load" corresponded with the position of the pin in the cross-arm, so that the strain was parallel to the grain of the pin. In the tests made, no particular care was taken to turn the pins in any fixed position relative to the grain of the pin and the direction of the strain applied.

For good construction on lines using 30,000 to 60,000 volts the larger pin must be used. It does not seem, however, that any good reason exists for a great number of different sizes of pins, as it would seem probable that the two sizes tested might be used to fulfil almost every requirement for transmission work where wooden pins are at all allowable.

In many respects an iron pin is better than one of wood. In the first place, to secure sufficient strength in the shank, the wooden pin must be of such a large diameter that the size of the cross-arm is necessarily increased. In addition, using an iron pin, the insulator can be held down on poles or supports where the tendency of the line wire is to raise or pull the pin out of the cross-arm. In using wooden pins, this is usually prevented by driving a nail through the cross-arm into the shank of the pin.

An iron insulator pin, possessing many desirable features, has been designed for use on the extensive transmission lines of the Vancouver Power Co., of Vancouver, British Columbia, the design being due to Mr. Wynn Meredith, of San Francisco. In general, the pin consists of a steel bolt approximately 12 inches long. A cast iron sleeve $4\frac{1}{4}$ inches long, and fitting closely to the cross-arm, fills the space between the thread, and corresponds to the stem of the ordinary wooden pin. The thread of the pin is made of lead, this lead thread being cast upon the end of the steel bolt, the steel bolt being first chopped or made ragged, so that the lead is held firmly to the steel bolt after being cast.

The tests upon this form of pin have not as yet been completed, but as soon as possible the results will be presented to the INSTITUTE.

MR. MERSHON:—The fourth and last written contribution to this part of the subject is by Mr. D. L. Huntington, electrical engineer of the Washington Power Company, Spokane, Wash.

MR. D. L. HUNTINGTON:—Wooden pins are subject to so many uncertainties when used in connection with very high voltages, especially where the atmosphere contains salt, smoke or dust, that it seems desirable to abandon their use for such purposes wherever possible, and to substitute a metallic pin. The construction of a long distance line for 60,000 volts, led the writer to make some investigation as to what could be done in this direction, without excessive cost.

It was decided that a drop-forged or a turned steel pin would be so expensive as to exclude it, even if the time at our disposal would have permitted us to wait for its delivery.

Experiments were made with a cast-iron pin almost identical in dimensions to that shown in Fig. 2 of Mr. Chesney's paper, except that it was cored out internally so as to make its weight about 10 pounds. The diameter of the shank was 2⅛ inches. This pin, before fracturing, sustained a load slightly in excess of 3,000 pounds, suspended from near the end of the threaded portion.

Fear was felt, however, as to what might occur under the sudden strain of a line parting in winter time, with the possibility

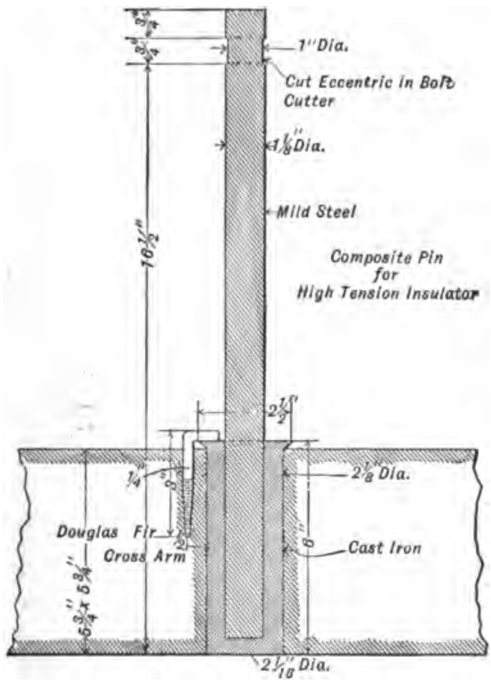


Fig. 1.

of the fracture of several pins at a time due to the sudden shock.

To avoid this, several designs were made of pins cut from round steel bars of 1 inch and 1⅛ inch diameter. The difficulty in obtaining a satisfactory shoulder for the pin at the cross-arm proved serious. Furthermore, it was feared that with a pin of that small diameter, the cross-arm would be likely to burn out at the pin-hole, as the interior surface of the hole would be comparatively small for distributing the leakage currents to the cross-arm. Moreover, actual experience with wooden pins has shown more or less conclusively that with a shank diameter of

two inches or greater, there is little or nothing to fear from this trouble.

As a result of these several difficulties we have designed and adopted a pin (see Fig. 1) eighteen inches long, made of $1\frac{1}{8}$ inch round mild steel bar, and having a shoulder and shank cast upon it as shown. This pin we find will begin to bend when loaded with about 1,000 pounds at the upper end, the shank being rigidly supported. This is much lower than the results obtained by the cast iron pin referred to above, but it is believed that it is more reliable and that it is sufficient for nearly all ordinary work. In addition, the steel bar will not snap off under sudden shock, but will support the insulator and line safely even when badly bent. We were unable, in the time at our disposal, to investigate what could be done in the way of malleable castings of a design somewhat similar to the cast-iron pin mentioned above, but it is the writer's opinion that it would prove a fruitful line of investigation.

High freight rates of the west and a higher initial cost will doubtless make some of those in charge of the construction of such lines hesitate at the extra expenditure (in our case it was about double the cost of eucalyptus pins), but it is in the line of safe and conservative engineering and certainly strengthens the weakest link in our high-voltage chain, our lines.

Mr. W. N. Smith:—It seems to me that the dimensions given are all very well for a pin carrying a certain weight of wire, but it does not seem to me that a single standard table of dimensions could be laid down to cover anything like all the conditions of various power transmission lines, all the way from a line of 5,000 or 6,000 volts, with, say, No. 4 wire, up to one like the Niagara Falls power transmission line, which is of 300,000 c.m. cable. The scheme of the tabulation should be enlarged and gone over carefully, so as to have a separate tabulation for a reasonably small range of weights of copper wire to cable; that is, one table for sizes from No. 6 to No. 3, another No. 3 to No. 0, another from No. 0 to No. 0000, and another from No. 0000 up. In this way the design of a standard pin would more nearly meet the varying conditions of transmission line construction. I remember reading Mr. Stillwell's paper a year or more ago on the Niagara Falls transmission plant, in which, if I remember correctly, he stated that the principal trouble with pins was their breaking at the root of the thread. I do not see that this point has been covered in Mr. Mershon's discussion, although it was referred to in Mr. Gerry's contribution. I should think it a matter of considerable importance in the design of the pin. I further agree with Mr. Gerry in his opinion that the top of the pin is rather small, certainly, for the very heavy insulators that would be required for a transmission above 30,000 volts.

Mr. P. H. Thomas,:—It would be a great gain to those who hope to get information from the report of the committee, if the characteristics of the different types of wood commonly used

could be discussed, *e.g.*, oak, eucalyptus and locust. It is to be hoped that in the local sections this question will be very fully discussed. Also, something should be said about the method of treating pins, which is one of the most important questions in the insulation of the line. The treating of pins to make them waterproof, without injuring the mechanical strength, is a difficult matter.

In putting up an insulator, where the pin comes to a bearing on its end inside of the insulator, expansion of the pin or contraction of the insulator may crack off the top of the insulator, especially with glass. To amend this difficulty, a shoulder might be arranged so that the pin would not touch the top of the insulator.

MR. MERSHON:—As to the question of the size of the pin, it may be desirable to have a pin larger at the top, perhaps, but I do not think the reason which has been given for this holds very well. In the first place, an insulator properly designed will not tip. If the insulator is designed so that the side pull of the line on it is transmitted directly to the pin, instead of being all the way from an inch and a half to two inches above the top of the pin, as in the case of most insulators, it will not tip. If it does, that is a fault in the design of the insulator and not in the dimensions of the pin. Mr. Gerry has criticized the shearing strength of the thread. I doubt if the thread of the pin proposed by Mr. Gerry will have a greater shearing strength than the thread of the pin referred to in the paper. The question of the shearing strength is not so important. A well-designed line will not have much up-strain. A line with much up-strain is not laid out as it should be. You cannot prevent some up-strain on some insulators, but it may be made so light that the shearing strength of the thread will not be of much importance.

VICE-PRESIDENT SHELDON:—If there is no further discussion, we will proceed to the next paper. Do you care to make any closing remarks, Mr. Mershon?

MR. MERSHON:—There was a further remark made by Mr. Gerry to the effect that it is too early to adopt a standard pin. I think if we adopted a standard and changed it from year to year, we should not be any worse off than we are now, when we have no standard. There are as many standards as there are manufacturers of pins and designers of pole lines. The only way now to get a pin to fit an insulator is to send the insulator to the pin manufacturer and in that way have the pins made so that they will fit. If you buy a pin from one manufacturer and the insulator from another, they may fit, or they may not fit.

VICE-PRESIDENT SHELDON:—We will now proceed to the discussion of the paper by Mr. F. O. Blackwell on "The Testing of Insulators." As Mr. Blackwell is not present and has not delegated any one to present his paper, I will call upon Mr. Mershon to present the introduction.

MR. MERSHON:—If there is no objection, I will pursue the same course in regard to Mr. Blackwell's introduction as with

my own. I will omit reading his introduction* and read the contributions to it. I think they take up most of the main points and will serve as a basis for the discussion this evening. The first contribution is by Mr. M. H. Gerry, Jr. It is as follows:

MR. M. H. GERRY, JR.—Mr. Blackwell has ably discussed a number of important matters in connection with the testing of high-voltage insulators. There are, however, a number of additional points which have not been touched upon.

Insulators are tested for two purposes: first, to determine the design, shape, material and dimensions best suited for a given voltage and set of conditions; secondly, insulators are tested as a matter of routine, to determine whether manufacturers have complied with specifications regarding material and workmanship.

There can be no complete set of tests to cover the first purpose, as it is not only a matter of experiment, but of skill and judgment in properly interpreting the results of many tests, in relation to service conditions. The testing of insulators for the second purpose is comparatively simple. For glass insulators it is usually sufficient to inspect them for physical defects, such as cracks, bubbles and incorrect dimensions. A certain percentage of the insulators should also be tested for proper annealing, and for mechanical strength. A chemical analysis of the glass of a few of the insulators is also desirable. Electrical tests of glass insulators are unnecessary, as the physical inspection will reveal everything that can be found by an electrical test. Porcelain insulators are more difficult to test than are glass insulators, on account of many defects being covered by the glaze. For very high voltages, porcelain insulators should be tested electrically, and should also be carefully inspected during the process of manufacture, and before the glaze is applied. This is especially desirable with insulators built up of several parts and cemented together by glaze or other material. Defects in insulators of this type are difficult to detect, even by electrical tests, unless they are pronounced.

Mr. Blackwell has indicated the proper method of making electrical tests of insulators. The puncture test mentioned by him, of twice the potential between wires, is usually sufficient, but a higher test is desirable where the insulators are to be exposed to severe lightning strains.

MR. MERSHON:—I would like to speak in regard to the following sentence in the contribution of Mr. Gerry, which has just been read. "The puncture test mentioned by him (Mr. Blackwell), of twice the potential between wires, is usually sufficient, but a higher test is desirable where the insulators are to be exposed to severe lightning strains." I have never personally known or heard of a case of insulators having been punctured where the puncture could be laid to lightning. It seems to me the lightning would flash around most insulators rather than puncture them.

* See page 6.

Then as to the question of the chemical analysis of glass insulators. I have never had any reason to think that the chemical composition of the glass made any difference in the behavior of glass insulators. I have made tests for difference in behavior due to composition on both insulators and tubes of glass, but never succeeded in finding any.

VICE-PRESIDENT SHELDON:—The subject is open for general discussion.

MR. P. M. LINCOLN:—I would take issue with Mr. Gerry, who made a statement that glass insulators did not need testing beyond visual inspection. I know of a certain line, the insulators of which were not given a voltage test, but were simply tapped with a mallet in order to eliminate, if possible, any which had undue internal strains. After the insulators were up and the normal voltage applied, quite a number of them broke down in actual service, which probably would not have occurred if they had been tested with voltage before being erected.

Another point, in regard to lightning, which Mr. Mershon speaks of—it is a fact that rain usually accompanies lightning storms, and that, of course, will give you a wet surface on the insulator. This wet surface is a very good conductor of the sudden surges which occur in lightning storms, so that lightning strains will be very apt to go over the surface rather than through the insulator. I do not think there is much danger of breaking down of an insulator from lightning strains, after a test of double normal potential has been applied.

VICE-PRESIDENT SHELDON:—Is there any more discussion?

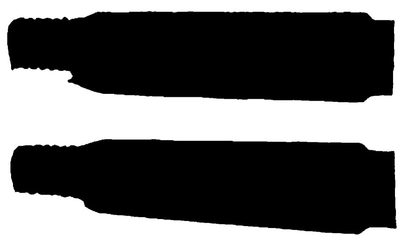
MR. W. N. SMITH:—While the subject is before the INSTITUTE, I think it would be quite interesting if any members present would state their preferences between porcelain and glass for high-tension insulators. It is a question that comes up every now and then, and no doubt there are members present who may have a very strong leaning toward one or the other material for high-tension transmission.

MR. MERSHON:—As between glass and porcelain, it seems to me about the only advantage, other things being equal, that porcelain has over glass for transmission work is that of mechanical strength. Sometimes it has that advantage and sometimes it has not. It is a fact, however, that in some forms of insulator—in some complex forms—it is possible to get the porcelain insulator cheaper than the glass one. I have found this true, to my surprise, in one or two cases. When the insulator is large, so that it takes the form of a very heavy central portion of glass, with long, thin petticoats, it seems to be almost impossible to make it of glass and have it symmetrical. The thinner portions cool first, and when the insulator is taken from the mold the weight of the outer portions distort the inner portion of the insulator, which is still hot. An advantage has also been claimed for porcelain over glass because of the lesser hygroscopic effects, but I think in most power transmissions the small amount of power necessary to dry up whatever moisture will get on the

surface of the insulator in that way would not be serious. As a matter of fact, in any measurement I have ever made, no difference could be detected between porcelain and glass in the matter of losses over their surfaces at high voltages.

MR. T. W. SHOCK:—I had the pleasure of building a line this last year in the State of Pennsylvania, in which I used an insulator which tested for 75,000 volts. The ordinary pressure will be 24,000 volts—that gives a factor of safety of over two. I think I agree with Mr. Blackwell, that in testing insulators for a line of high pressure the testing pressure should be at least two and possibly three times the ordinary line pressure. My idea in adopting that style of insulator is due to the fact that it was built for a line on the Pacific coast, for 40,000 volts, and I adopted it to give me an extra factor of safety. I made the test at a pressure of 75,000 volts. I think the insulator will give us very good satisfaction.

MR. F. N. WATERMAN:—Mr. Blackwell's reference to testing a double insulator—an insulator primarily of two parts—



Broken 10½" pins (Stem.) Total Length, 15¾" Showing How Pins Split.

requiring that each part should be separately tested, seems to me practically to bar out double insulators and does not seem to be logically founded. He says, "if it is to be tested for 100,000 volts and is made in two parts, each part might, for instance, be tested with 70,000 volts. The object of this is to have the weak parts rejected before they are assembled." The objection to that, from a practical standpoint of course, is evident; but there is a further objection, not so evident, and that is, as I understand the porcelain people, in the baking or vitrifying of the two parts it is not desirable to take the entire shrinkage out on the first heat. Consequently, if the insulators are to be tested before being filled with glaze and re-vitrified, they are not tested at all in their final condition. Furthermore, I think it is illogical for the reason that it is a well-known fact that if we get porcelain in thin parts, we have a very much more than equal chance of getting sound porcelain. That is, if the same insulators were made in one part they would only have our final test, while the double insulator with much greater initial

chance of being sound is required to be tested twice. The test peculiarly required by the double insulator is the mechanical test, and as far as my observation goes—I have tested a good many of them—if they are substantially free from large air spaces, they will stand up under the final electrical test. It seems to me that the requirement of a double test is unfair and unnecessary.

Mr. Thomas:—Mr. Gerry, Mr. Lincoln and Mr. Mershon have referred to one point in the testing of glass insulators that deserves a good deal more consideration, and that is the initial strains left in the manufacture and annealing of the glass. The breakage of glass insulators on the line during service may more often be due to too much sun on one side of a poorly annealed insulator than to electrical strain. I do not know of any test which has been suggested to determine whether glass has been properly annealed or not, but I do not doubt that some test could be gotten up, and I make the suggestion to the committee that they consider this point carefully. A successful test would save a great deal of trouble in high-tension lines after the insulators

Iron-Pin Insulator.

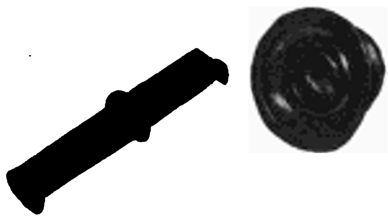
are installed. There is one rather old point which should be mentioned in the testing of porcelain insulators—not only should they be tested with salt water, but the regulator should soak a certain definite time; the Standardization Committee might determine how long.

Mr. C. C. Chesney:—A glass insulator, if it is not properly and uniformly annealed, has unequal strains in the different parts of the glass. I have known a number of such insulators after a cool night to break when the sun struck them in the morning. The side towards the sun cracks off. Aside from this feature, I believe a glass insulator will give as good satisfaction as a porcelain one.

Mr. Mershon:—I cannot entirely agree with the author in regard to the use of one transformer for testing purposes. A series of transformers need not have a bad regulation or seriously distort the wave form, and such a testing set has a very great advantage that a transformer breakdown is much less serious than in the case of a single testing transformer. The knowledge

of this fact gives one more confidence in testing, especially in experimental testing. For very accurate results in any case a step-down voltmeter transformer is desirable.

Neither can I agree that insulators should necessarily be tested on iron pins. As I have stated before, an iron pin is likely to be the means of putting upon the insulator a mechanical stress all out of proportion to any which it would meet in practice if installed upon a wooden pin. For instance, if the insulator be screwed down tight upon a metal pin there will result stresses in the head tending to force the top of it off either at one of the threads or at the bottom of the pin-hole, or tending to burst the head. In either case there is a resulting mechanical strain in the substance of the insulator inviting puncture perpendicular to the lines of stress. An insulator that will stand up well under a salt water test, will often break down quickly when tested on a metal pin. While I do not believe in depending upon the wooden pin for insulation, I see no good reason for condemning it in general where there will be no

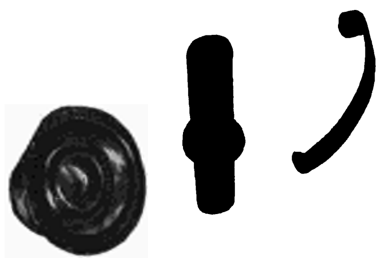


Parts of Iron-Pin Insulator.

trouble from burning. The author says that wooden pins burn off eventually unless the insulator be good enough to be used with an iron pin. If the insulator be good enough to prevent burning of the wooden pin, why not use the wooden pin unless there be some mechanical requirement which it cannot meet.

I agree thoroughly that any new type of insulator should be given a rain test; that is, a voltage test while water is being sprayed upon the insulator in imitation of rain. If a wooden pin is used in this test, it should be covered with tin-foil from a point inside the petticoat nearest the pin to a point two or three inches below. The voltage should be applied between the foil and a wire around the neck of the insulator, or, preferably, between the foil and a piece of wire representing the line wire and tied to the insulator as it will be in practice. The recommendations of the Introduction as regards the angle at which water should be sprayed, is all right, if this angle be uniformly adopted in testing; but some definite angle should be adopted, as the angle makes considerable difference in the voltage at which the current will arc from the line wire to the pin. The recommendations in

regard to the spray are not, however, so specific as could be desired. The amount of water sprayed, as well as the angle, makes a difference in the arcing voltage. Some time ago I endeavored to obtain from the United States Weather Bureau information as to the most violent precipitation on record in this country. The record sent me showed the most violent downpour as being about .8 of an inch in five minutes. The maximum rate of downpours during that time may, of course, have been greater than this. It has been my practice to endeavor to adjust the spray for a precipitation of one inch in five minutes. This can be most conveniently done by placing under the insulator a suitable pan and collecting in it the water for five minutes. Care must be taken that in placing the pan it does not receive water from any part of the cross-arm other than that just over it. The question of the method of obtaining the spray is one which it is well to consider. It is no easy thing properly to adjust the spray from an ordinary garden spray-nozzle or rose-spray and it is no wonder that uniform results are not



Parts of Iron-Pin Insulator.

easily obtainable. It is desirable, if possible, to have some special form of spray-nozzle which will give a uniformly distributed spray. This might perhaps be in the form of a very large rose-spray of a foot or more in diameter.

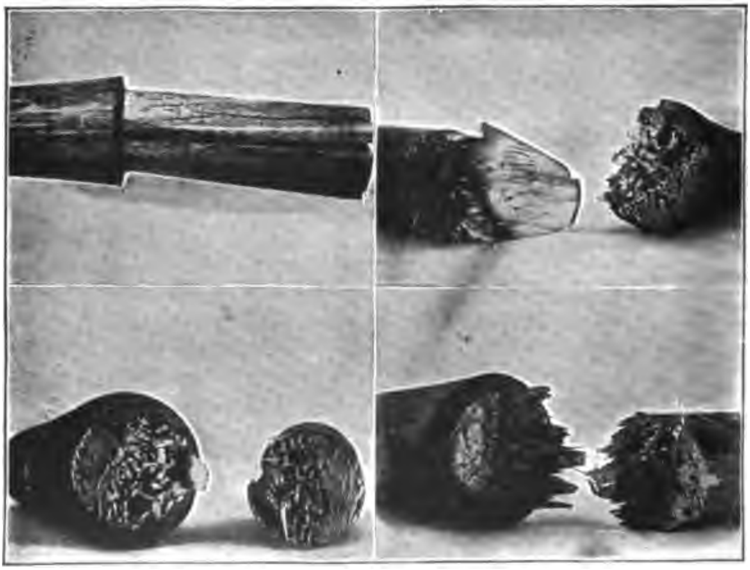
It is desirable that if possible we arrive at some definite decision this evening on the points mentioned in regard to the methods of testing insulators, so that recommendations can be made on this subject to the Standardization Committee.

Vice-President Sheldon:—There is a written contribution on this subject from Mr. W. L. Waters, of Milwaukee, Wis.

Mr. W. L. Waters:—The form of potential wave given by modern alternators differs very little from a sine wave. The worst case commonly met with is that of a three-phase alternator wound for high voltages. These machines have usually three slots per pole, and the wave form shows pronounced harmonics of five and seven times the fundamental frequency, but the effect of this distortion on breakdown voltage of an insulator is inappreciable. The only commercial machines that have wave

forms which would affect the accuracy of the results to any extent are the old single-phase revolving armature machines with projecting poles on the armature, which show a pronounced third harmonic. But these machines are seldom met with now. The charging current in a test on insulators or an overhead line generally conforms more or less to the potential wave form of the alternator, and whether the current is lagging or leading the distorting effect on the wave form is slight, and with all ordinary excitation and loads on the alternator the effect on the insulator test will be inappreciable.

Generally speaking, an insulator will stand momentarily a voltage strain which, if continued long enough, will break it down;



1. Pin Split in Shank and Broken at Cross-Arm.
2. Pin Broken at Upper Part of Shank at Cross-Arm.
3. Pin Broken at Upper Part of Shank at Cross-Arm.
4. Pin Broken at Upper Part of Shank at Cross-Arm.

and this time effect is most marked in solid insulators. A gas such as air does not show this. When air is going to break down under a given strain, it will do so almost as soon as it is applied, except where the insulation of the air is subsequently weakened by a violent brush discharge. Solids show this effect to the greatest extent, and liquids such as oil to a lesser extent. And I have found that in insulating materials where this effect is most marked, differences in wave form have little effect upon the breakdown voltage; it seems to be the mean voltage or possibly the r.m.s. voltage which decides the breakdown. In air the wave form has quite an appreciable effect, and the difference between a peaked wave and a flat wave may be as much as

20 per cent. of the sparking distance. Porcelain insulators show very markedly this time effect; they will stand a much higher potential if applied instantaneously than they will if applied continuously, and as far as can be seen from the experiments I have made, they appear to conform with the rule mentioned above, and are practically unaffected by wave form. The sparking distance in air, on the other hand, being considerably affected by wave form, shows at once the unsuitableness of using a spark gap as a voltmeter if there is any doubt about the wave form. And I have found that unless it was in the hands of a very careful and experienced man, a spark gap was not of very much use in accurate work. Using needles as electrodes, the voltage seems to vary so much with the condition of the points, the state of the atmosphere, the proximity of other high tension conductors etc., that consistent results cannot be obtained in ordinary work. Using amalgamated brass balls, one inch in diameter, gave better results, but they are far from satisfactory. I think there is only one really satisfactory way of measuring high voltages, and that is by means of a voltmeter transformer connected straight across the insulator being tested. This method is accurate and is direct reading, and there is no chance of mistake and no continual trouble fixing and adjusting your spark gap. Reliable voltmeter transformers can be made for all ordinary voltages for a few hundred dollars, and the use of one would save its cost in worry and hard work in a very short time.

The above remarks are, strictly, only applicable to voltages up to 50,000, as I have had no experience with higher voltages. But I think that with slight changes they will apply to the highest voltages at present in use.

VICE-PRESIDENT SHELDON:—We will now take up the paper by Mr. P. M. Lincoln, entitled, "Transposition and Relative Location of Power and Telephone Wires."

Mr. Lincoln read his introduction (see page 11), and the following contribution by Mr. M. H. Gerry, Jr.

MR. M. H. GERRY, JR.:—Mr. Lincoln has discussed the most important requirements of telephone construction in connection with high-tension transmission lines. There is no especial difficulty in installing a successful telephone circuit which will give satisfactory service and reasonable safety in operation on a pole line carrying from 50,000 to 60,000 volts.

Mr. Lincoln has mentioned the principal requisites of successful design, which are a proper adjustment of the capacity, a maintenance of high insulation from ground, and a complete transposition of the telephone wires in reference to each other, to the power circuit and to the ground. In addition, might be added the use of certain safety devices, which reduce the danger in handling telephones connected with circuits on high tension pole lines.

In regard to transpositions: Mr. Lincoln advocates the transposition of the telephone wires only, but it is desirable also to transpose the main power circuits, in order to reduce to a mini-

mum the voltage to ground on the telephone circuits. But few transpositions of the power circuit are required, and the service as a rule is materially improved thereby. Where there is considerable lightning, arresters should be installed on the telephone circuits of a design similar to those used on lighting circuits. The ordinary telephone lightning arrester is an undesirable and unsafe piece of apparatus for this purpose. Fig. No. 7 is a sketch of a telephone arrangement devised by the writer, which will give excellent results in service. Especial attention is called to the short gaps across the line, to the location of the lightning

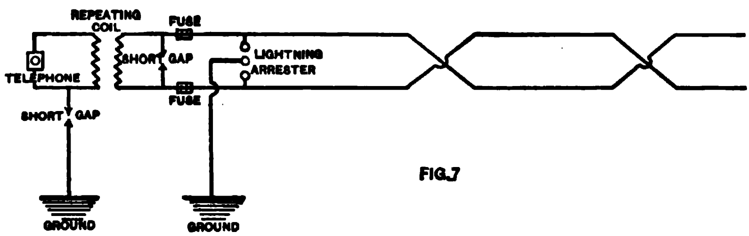


FIG.7

arresters, and to the repeating-coils, which should be insulated for at least 5,000 volts, and may be immersed in small glass jars containing transformer oil.

The Missouri River Power Company, with which the writer is connected, regularly maintains a very satisfactory telephone service on its 50,000 volt transmission lines between Canyon Ferry and Butte, a distance of sixty-four miles, and this service is rarely interrupted, even during the most severe lightning disturbances. Under normal conditions, there is no potential on this telephone line, and only the slightest hum can be detected.

MR. LINCOLN:—There is one point upon which possibly my discussion is not quite clear, and that is in regard to the transposition of the power circuits. I have stated that it is not of very great importance. My reason possibly is not very clear in the paper, and it is this—a telephone line ought to be so made that it will at all times operate, even if one leg of the power line is dead grounded. If it is made to operate under these conditions it will operate under the normal conditions of an untransposed power line, because the normal static potential induced in the telephone line by an untransposed power line is vastly less than that which will be induced in the telephone line by grounding the power line; so that if the telephone line is installed so as to run under grounded conditions, that is, with the power line grounded, it will certainly run with an untransposed power line.

VICE-PRESIDENT SHELDON:—The subject is now open for general discussion.

MR. RALPH D. MERSHON:—The truth of the observations of paragraph (6) is not clearly evident to me. The relation between the telephone circuit and the power circuit is, as stated in paragraph (4) such that in their electromagnetic relations they con-

stitute a transformer—an air-core transformer and one having very poor regulation. This transformer has in its primary—the power wires—a current unaffected in value by any current in the telephone wires and which may therefore for any given condition of power load be considered as a constant current. If the telephones took any appreciable amount of current, an amount comparable to the power current, we should have a tendency toward constant current in the telephones. If, as is the case, the telephones take a current very much less than the power current, we will have a tendency for constant voltage.

Electrostatically, each telephone wire is a plate of a condenser, the power wires being the other plate. These two condensers are in series through the telephones and have impressed upon them a constant e.m.f. The condition here is similar to that for the electromagnetic action, in that if the current in the telephones be such as will convey a charge approximating that which the impressed e.m.f. can impose upon the condensers, there will be a tendency toward constant current; if not, as seems to me is usually the case, there will be a tendency towards constant voltage. In short, it seems to me that the conditions are about the same in the case of the electromagnetic and electrostatic disturbances. This is on the assumption that the reactance of the telephone is low relative to its resistance. If this is not the case, and the reactance is comparable to the condensance concerned in the telephone circuit, then the current conditions may be almost anything, depending upon the relations between these two quantities Further, if by telephones of various resistances it is meant to designate telephones of various numbers of turns in the transmitter, then it seems to me the statement in regard to the disturbing ampere-turns is incorrect. The resistance of a coil varies as the square of the number of turns (assuming the same space available in each case for copper). The ampere-turns on constant e.m.f. vary, therefore, inversely as the square root of the resistance. It would seem, therefore, that if, as stated above, the electromagnetic and electrostatic effects are constant potential in their nature, telephones should be wound for as high resistance as possible. This seems reasonable, as it is equivalent to saying that the telephonic e.m.f. should be kept as high as possible, which in turn is equivalent to saying that the disturbing e.m.f. should be as small a percentage of the telephonic e.m.f. as possible. In order to solve some of these questions, it is necessary to know the current and e.m.f. of telephones. I have no such data and have not been able so far to obtain them.

(7) It does not seem as though the objection given for the use of the series telephone were a valid one, since one ought not to introduce a telephone at B, Fig. 2, any more than one would connect a bridging telephone at this point. In other words, telephones, whether series or shunt instruments, should be connected at even transpositions in order to obtain the best results.

(14) It is not quite clear to me why the series telephone should

not be a satisfactory instrument. As has already been stated, the reason mentioned in (7) seems hardly a valid one for condemning it.

(15) There is another method of accomplishing this desired end of having the telephone lines as nearly as possible at the same potential as the earth, which seems preferable for the use of a grounded wire; first, on the score of simplicity, and secondly, because it may also be a means of protection against loss of life or fire. This method is that of using autotransformers connected across the telephone line at a number of points, preferably at each of the telephone stations, each having its middle point connected to ground. Each transformer should be designed so as to take a very small amount of the telephonic current, but should have wires sufficiently heavy to enable it to take, in case of a cross with a high voltage wire, a current heavy enough to operate the circuit-opening devices in the power station or else to blow a suitable fuse in the telephone circuit itself. Such a device would protect the users of the telephones from disagreeable or dangerous shocks, whether due to crosses, leakage or electrostatic induction, and would also help to minimize disturbances due to grounds, etc.

Mr. P. H. Thomas:—I think that the subject of telephones on long distance power transmission lines is perhaps the most important subject we have to-night. Mr. Lincoln has given a very good statement of the fundamental principles underlying the difficulties that have been found in many cases. By exchanging experiences and making suggestions, we can probably base on these fundamental principles improved methods by which the present service can be very much benefitted. As Mr. Lincoln concludes, I think there is no doubt that the trouble is chiefly due to the electrostatic induction from the normal voltage which tends to raise both telephone wires above the earth, either positively or negatively. There will also be a momentary disturbance whenever we have a charge of a lightning arrester, or any static discharge, in the neighborhood, but that will not give much trouble as regards clearness of communication, because it is over quickly. The transposition of the transmission line is, I think, an important point practically in high-voltage transmission. As Mr. Lincoln states, a telephone circuit *should* be built to work under all conditions; for instance, when one line is dead grounded. But if it is impossible to make it work at such times, and if you can make it work smoothly when not grounded by transposing the power line, you had better transpose it, and that is the actual condition of practice.

Assuming both telephone wires are going to reach high potential above the earth, there is only one thing to do to get service at all times, and that is to eliminate the baneful effects of the high potential.

I will make a suggestion for accomplishing this purpose, which may not have much practical value, but should be worth trying.

I hope that some of the engineers who have opportunities for experimenting at hand will try it for their own and the general good. For instance, it is possible we may be able to insulate the telephone wires, perhaps for 30,000 or 40,000 volts in an extreme case, and at the end of the line put the primary of a transformer and connect the telephone to the secondary, thus making very high insulation between the primary and secondary. By this means it would be possible to protect the operator, and since static disturbances do not induce potential between the two wires, it should not disturb the speech. The same result may possibly be accomplished with condensers, by connecting two condensers in series between the two pair of wires and putting the telephone in between the condensers, not connected with the line. In this case it will probably be necessary to put a choke-coil between the condensers and ground its middle point. The charging current of the condensers will be neutralized by going through the two halves of the coil in opposite directions and a telephone winding could be taken from the same core.

Mr. Lincoln suggested carrying ground wires in close proximity to the telephone wires. This should help much and would be a good method to try, but it would probably be necessary to use insulated wire for the telephone circuit, otherwise there would be trouble from repeated grounding. One method, which would be effective, but perhaps not practicable, would be to use for each side of the telephone wire a twisted pair; one wire of the pair for the telephone circuit and the other of the pair grounded. This method would make a large capacity between the telephone wire and ground, but would not actually ground the telephone wire itself.

There is another interesting possibility for those who like to speculate. Can we not use the power transmission wires themselves for sending signals? If not for telephoning, at least for general signaling. For instance, as a suggestion, we might connect a high resistance between each wire and a common point, and connect this point to ground, and similarly at the other end; then put a high frequency generator between the ground and the common connection at one end of the line, and some kind of receiving apparatus in the other. The high frequency would prevent the transformers from taking too much current, and you might be able to signal when power was on the lines. The same thing might be done with condensers or choke-coils. The advantage of using all the wires in parallel for signaling is that if you have three or four wires burnt off, there might yet be one wire you could signal through.

Another point is, it would be possible to make temporary arrangements for signaling in times of shut-down, until the power comes. That is, when voltages go off, it would be possible to use the dead wires to make arrangements to start up again. Things are in a critical state when the power is off, and the telephone lines down, and such a system of signaling might easily be arranged.

Another thing is very important, and that is the protection of the man using the telephone. One or two fatal accidents have recently occurred to operators on the telephone circuits. They should either be insulated in a booth, or the circuits should be dead grounded, or protected through an air-gap small enough to be safe for the operators.

In regard to Mr. Lincoln's statement that telephone wires may reach as high a voltage as 20,000 volts. It occurs to me that as perhaps his statement is based on theoretical considerations, I can emphasize it by stating that I have seen this voltage in fact, in Mr. Gerry's plant. I have seen sparks from telephone line to ground which were something like half an inch long, indicating perhaps 20,000 volts, perhaps higher than that. The possibility which Mr. Lincoln describes is not at all imaginary; it is very real.

Mr. C. E. Skinner:—I wish to emphasize the last point made by Mr. Thomas, that is, the protection of the workman. The insulation of the instruments in the building has been mentioned by Mr. Lincoln. The insulation of the workman is even more important, and it is not difficult to make arrangements so that he will be well enough insulated, so that even a cross between a high potential line and a telephone line will not do serious harm. It is usually painful to receive a shock of this character, but not particularly dangerous. It has been my observation that men handling telephones on high-tension transmission lines, soon learn to be very cautious and are usually compelled to watch the surrounding material, walls, etc., when telephoning. This could be easily avoided by proper arrangements, so that the man need not touch anything which would connect him to the ground.

Mr. C. O. Mailloux:—I would like to mention a phenomenon in connection with the charging of lines which, while not exactly within the scope of this paper, is still interesting, especially as it is a phenomenon which has puzzled me and which has puzzled others to whom I have mentioned it. I have observed the fact that the transmission line will become spontaneously charged electrostatically without being connected to any generating machinery. About a year ago, in Arizona, we repeatedly observed that the three wires of a 25 or 26 mile line would become charged spontaneously to a considerable potential under various atmospheric conditions. In Phœnix, Ariz., at this time of the year, the weather is very much the same as it would be here in June of July, except that there is no rain. The weather is usually very pleasant, quite warm in the day time—one can wear summer clothes—and it cools but very little in the evening. There are occasionally slight winds, especially over the deserts, over a portion of which the line runs. I have repeatedly observed, but during the day time only, or until early evening, that the three lines became charged electrostatically. They could be discharged by making a connection to earth, but if left

alone they would soon charge again (in 10 to 15 seconds). The three wires would always charge at approximately the same potential with respect to earth, but this potential varied, as might be expected. It depended on the weather apparently, and varied, of course, with the length of time allowed for recharging. On one occasion, when there was a heavy wind preceding a rain, the potential was so high that we got sparks an inch and a half between the lines and the ground, through spark gaps. I have repeatedly observed cases where the spark was 1/16 to $\frac{1}{8}$ of an inch between sparking points. There were no indications of lightning or storm. There have been cases where the phenomenon was observed when it was raining, (at the distant end, which is near the mountains, where it rains occasionally), or shortly after it had rained; but the phenomenon was never so marked at such times; it was repeatedly observed when there was no indication of rain whatsoever, the sun shining brightly, but there was then always some wind or slight breeze somewhere along the line. My own theory was that the charge was either caused or translated by the wind, and taken up by the wire surfaces acting as condensers. I have mentioned the matter to several physicists, but my theory was rejected, as moisture in the air is considered indispensable, and it was lacking in this case. I have not succeeded in getting any satisfactory explanation. I hope there is someone here this evening who may be able to give it.

Another interesting phenomenon which I have observed in the same climate is the fact that the lightning arrester, which is located at each end of the line, has generally a tendency to frying discharge, which is more pronounced between the lightning arrester gap of one line than of the others. It was not always the same line, but changed from one line to another. I could not determine with the facilities we had what that was due to, but I was tempted to ascribe it to some sort of electrostatic action. The three line wires were systematically transposed in building this line, so as to bring an equal length of each of the three wires in the same relation with the surface of the ground.

Mr. Lincoln:—The point has been brought up about the use of series telephone versus the bridge telephone. I know by bitter experience that the series telephone does not give very good satisfaction. I once had charge of a line on the poles of which was run a telephone line, and on that telephone line we had about fifty series 'phones scattered along over twenty-five miles, about half a mile apart. We were never able to get successful service from that system. I ascribed most of the difficulty to the fact that the talking current had to go through so many loose contacts, so many jacks, and it is almost impossible to keep so many contacts in good shape. With the bridge 'phone it is necessary for the speaking current to go through only one pair of loose contacts or jacks at each 'phone. That constitutes one great advantage of the bridge over the series telephone.

The suggestion has been made that the potential between telephone wires and ground can be reduced by introducing between them autotransformers or condensers or resistances and connecting the middle points of these autotransformers, etc., to ground.

The objection to that method, it occurs to me, is that it takes off the charging current at concentrated points. The current is induced in these telephone wires as a distributed effect, distributed along the whole length; and if you try to take it off at bunched points, there will be a flow of current in the telephone wires which will introduce an e.m.f. and probably make disturbance in the telephone. The remedy which I proposed is to run a ground wire along the whole length of the telephone wire, producing a distributed capacity which will take care of the distributed induced effect most efficiently.

MR. MERSHON:—With regard to the use of condensers on telephone lines, it seems to me we want to keep the capacity of the telephone lines as low as possible to get good operation of the telephone.

If any one wanted to signal with the power lines, it would be better to signal from neutral to ground, and receive messages at the corresponding place at the end of the line.

I do not think the objection Mr. Lincoln makes, relative to the use of autotransformers on telephone lines, that the current would be drawn off at certain points, whereas it is introduced uniformly along the telephone line, would hold, as the current is flowing in the same direction in both telephone wires, and the effects of the two currents will neutralize each other so far as the telephones are concerned.

VICE-PRESIDENT SHELDON:—We will now proceed to the consideration of the paper on "Burning of Wooden Pins on High Tension Transmission Lines," by Mr. C. C. Chesney.

Mr. Chesney presented his paper (see page 18) and read the following contribution by Mr. M. H. Gerry, Jr.

MR. M. H. GERRY, JR.:—On a certain number of high-tension transmission lines there has been burning of the wooden pins. On other transmission lines of high voltage, there has been no such burning. Where burning has occurred, it has been due to leakage of current from the surface of the insulators, coupled with resistance conditions in the pin, such that sufficient heat was developed to char the wood.

When thoroughly dry, wood is one of the best of insulating materials, and one of the poorest when containing sap or moisture. The greatest objection to it is its unreliability, due to the difficulty of removing the last traces of sap or moisture. A thoroughly dry wooden pin, fifteen inches in length, will stand indefinitely 100,000 volts pressure, while a green pin of the same length, containing sap, will break down very quickly under 1,000 volts pressure. Paraffining the pins on the outside, or coating with asphaltum or linseed oil, is of no value. If the pins

are thoroughly dry, the material in which they are dipped can be made to impregnate the entire body of the wood, thus producing a pin of high insulation. Such a pin is of value, as it reduces the static strains on the insulator and decreases the amount of leakage to ground.

In order to prevent burning of pins they should have either very high or very low resistance. With insulators having a large amount of surface leakage, such as those illustrated by Mr. Chesney, an iron pin is perhaps the only solution of the difficulty.

There is nothing especially mysterious about the burning of wooden pins on high-tension lines, as it is merely a matter of total resistance to ground and the relative resistances of the insulators, pins, cross-arms and poles. Wherever burning occurs, it can be remedied by altering the design, material or dimensions of the insulators and improving the quality of the pins.

Mr. H. W. Buck:—Referring to the point which Mr. Chesney spoke of in regard to the so-called " digesting " of pins, I have seen many pins taken from the Niagara-Buffalo transmission line where such disintegration had occurred, the top of the pins having crumbled into a white powder. We have recently had some of this powder analyzed by a chemist and it was found to be a nitrate salt. This would look as if nitric acid had been formed in the presence of a static discharge inside of the insulator by the well-known atmospheric reaction and had attacked the wood, forming the nitrogen salt in combination with the vegetable matter of the pin.

In this connection I would like to say that about six months ago we built an experimental single-phase line at Niagara, about two miles in length, and operated it continuously for nearly four months at approximately 75,000 volts. The conductors of this line were galvanized iron wire, tied to the insulators with copper tie wires. At the end of the experimental run, the galvanized iron wire had turned black to a considerable depth throughout its length. The copper tie wires had also been attacked, though not so much as the iron. This surface disintegration was not due to general atmospheric influence, for iron wire in the same place but not charged electrically retained its original bright condition. I believe that this action is also due in some way to the influence of nitric acid formed by the brush discharge around the conductor. It indicates that some trouble may be experienced at such excessively high voltages where static discharge from the line is active. This discharge probably causes a combination of the oxygen and nitrogen of the air which, with the moisture of the atmosphere, forms a film of dilute nitric acid surrounding and attacking the metallic conductor.

Mr. Lincoln:—Mention has been made by Mr. Chesney and in the communication of Mr. Gerry as to the treatment of pins. I think the treatment of pins should be with a view to making them durable rather than making them good insulators. The pins should not be relied upon as a part of the insulation. As

long as they are dry and as long as the weather is perfectly dry, they may be most perfect insulators, but as soon as rain comes and the pins are wet on the surface even, they become practically useless as insulators and the entire insulation strain on the line falls on the insulators. We should treat the pins, therefore, with a view to preserving them rather than making insulators of them.

Mr. Mershon:—It does not seem that, as Mr. Lincoln stated a few minutes ago, when the arms and pins get wet, the insulation is all in the insulators; because if this were the case, I do not quite see how the sides of the pins next to the sea should be burned, and the sides away from the sea should not be burned. It seems to me it would be the other way. If the insulator controls the current, the lower the resistance of the pin, the less burning, and when the pin is charred all over there should be less heat generated on the surface, and consequently less tendency to burn. But if the pin does to some extent control the current, the lower the resistance the greater the current over the surface, and the more likely it is to burn, especially over any part of it which has had its resistance lowered.

The path of the leakage current from wire to wire of a power transmission line may be considered as a high resistance electric circuit, derived from a constant potential source. The total resistance of this derived circuit is the series of the resistance of the three elements, insulators, pins and cross-arms. The resistance of each of these elements is that resulting from two resistances in multiple; namely, the resistance of the element through its substance and the resistance over its surface. The substance resistance of all the elements is usually high, so high in a well constructed line that it need not be considered.

The surface resistance of the three elements may or may not be high, depending upon the surface conditions as regards moisture, dust, dirt or other deposits. Suppose the surface conditions of all the elements is such as to allow considerable leakage. No harm will result to the insulator unless the leakage becomes great enough to start an arc. This is not the case, however, with the cross-arms and pins. The leakage over their surfaces, if great enough, will char all the surface over which it passes. Pins are more likely to char than cross-arms, since their surface is less and their surface resistance, therefore, higher than the cross-arms; the result being, for a given leakage current, more loss per unit area of pin surface than of cross-arm surface. Any protected portion of the pin is especially liable to charring. For, if the cross-arms and pins have their exposed surfaces pretty thoroughly wet or dirty, so that the current passes over them with little resistance, the wet or dirty portions may be little affected; but if in the course of its path the current encounters any small portion of the pin which is not wet or which for any reason has a higher resistance per unit of length, the wood may be charred at this point. Now, this is what happens when the pins burn. The insulator, the lower part of the pin, and the cross-arm have their

surface resistance lowered by moisture or otherwise, but the upper part of the pin being protected by the insulator does not have its surface resistance so much decreased; the consequence is burning of the protected surface. In some cases the inner surface of the insulator next the pin and the pin itself are so well protected by the insulator that the current, instead of leaking over the surface of the insulator until it reaches a point where the insulator and pin are in contact, jumps in a brush-discharge from the edge of the petticoat to the pin rather than follow the higher resistance of the protected surface. As a result, the pin is burnt at the point where the brush discharge strikes it instead of at or near the thread. There are apparent three possible remedies for the trouble due to charring pins.

1. Make the design and size of the insulator such that for all conditions its surface resistance will be so high as to control the leakage and keep it below a point which can harm the pin.
2. Make the pins fireproof, but non-conducting.
3. Make the pins conducting.

The remedy recommended in the introduction to this discussion is (3). It is recommended that an iron pin be used. This certainly would do away with the trouble of charring pins, but whether or not it will introduce other and more serious trouble remains to be seen. It seems to me there is a very likely chance of trouble from the use of iron pins, due to the unyielding character of both iron and porcelain or glass and their widely different coefficients of expansion. Insulating material under mechanical stress will generally break down under a lower voltage than when not strained. An insulator or an iron pin might, when installed, be put under a considerable mechanical stress or one which when first installed has comparatively little stress upon it may, due to changes of temperature, be much strained; the result in either case is increased liability to puncture.

The endeavor may be made to get around this trouble by using a wooden thread upon the iron pins, but as shown by one of the cuts in the introduction, the charring trouble may still remain if this course is adopted. If a wooden cross-arm is used with the iron pin, the seat of the charring trouble may be transferred to the cross-arm unless the pins be connected by a conductor. It would seem better to adopt the first remedy and make the design of the insulator such as to protect the pins.

Mr. de Muralt:—It may possibly interest you to know that while the general practice in America is evidently to use wooden pins, in Europe it is just the opposite. Practically all the high potential installations use iron pins, and more than that, while here very often the whole pole is treated with as little iron as possible, in Europe there are quite frequently poles constructed entirely of iron, with iron cross-arms and iron pins, and the only insulation relied upon is the insulation proper. I believe this does away with the burning of pins, cross-arms and poles. I do not think there is very much difficulty in the way of avoiding

mechanical strains, which have been alluded to several times to-night, with regard to fixing the insulator in the pin. One way to get around that is to fix the pin into the insulator by means of a cement which will take up any such strain, and in a great many installations that I know of a cement made of a mixture of litharge and glycerine has been used with, as far as I know, very good results. It seems to me that it is a very fair scheme thus to lay the entire insulation into the insulator, and then let the rest of the pole take care of itself. I know of one installation, where they are operating at 26,000 volts, using American glass insulators and iron pins and iron poles; and of another one which is using 25,000 volts, and has porcelain insulators, with iron pins on wooden poles part of the way, and iron pins in walls and on any kind of a support on the other portion of the road. Neither of these installations has given any trouble whatsoever and they are amongst some of the best high-voltage installations in Europe.

Mr. Philip Torchio:—I want to suggest an explanation of the burning of the wood between the iron pin and the porcelain base in the Locke insulator shown in Fig. 3 of Mr. Chesney's paper. I wish to call attention to the fact that, if two plates are maintained at a certain difference of potential, acting as condensers and spaced at such a distance that there will be no discharge between the plates, but set near the limit at which the discharge would begin and then there is inserted in the middle a plate of vulcanized rubber, which has a higher dielectric resistance than air, right away the discharge takes place between the plates. Now, that is contrary to what might have been expected. The explanation is that before the insertion of the vulcanized rubber plate the fall of potential between the two plates of the condenser is a uniform straight line, but when we introduce the vulcanized rubber plate we alter the conditions, as we have then three condensers in series, which will distribute the total fall of e.m.f. in inverse ratio to their capacities. Therefore, this plate of vulcanized rubber acting as a condenser with a larger capacity than the same amount of air which it displaces will be charged at a smaller fall of e.m.f. between its faces than existed before, and the e.m.f. between the outer condensers will be increased and then the discharge begins. Now, it seems to me that in the Locke insulator, with double porcelain petticoats and an oak thread between iron pin and porcelain, there are present the conditions of several condensers in series which might give rise to a lack of uniformity in the distribution of e.m.f. between line wire and iron pin and cause the charring of the wood at the base of the insulator.

Mr. C. E. Skinner:—I understand that the pins used on one transmission line were selected with the utmost care, and were most carefully treated, and that they have had practically no trouble whatever in more than a year's run with a potential of over 50,000 volts. These pins are protected from the weather

by glass sleeves. We should keep in mind that this is in a different climate from many other installations, and that a cure for these troubles in one climate may not be a cure in other climates.

MR. W. N. SMITH:—In the matter of wood and iron pins, it seems to me that along with various other elements the question of cost will govern. Iron poles in this country at this time cost anywhere from $30 up, and a wooden pole of suitable size runs from perhaps $7 to $20, according to size and where it can be obtained. The size of cross-arms may be governed to some extent by the size selected for the butt of the pin. If you determine first on the size of the shank of the pin that enters into the cross-arm, that in a measure determines the thickness of the cross-arm, if of wood and larger than usual. That may mean quite an additional percentage to the number of feet of lumber to be bought to provide cross-arms for a long pole line. Lumber is higher than it used to be, so that there are considerations, commercial as well as techincal, that these various elements of design all enter into. The cost of selecting some particular pin because it looks a little better may thus run into some thousands of dollars on a long pole line.

VICE-PRESIDENT SHELDON:—We will now give Mr. Chesney an opportunity to close the discussion on his paper.

MR. CHESNEY:—I was particularly interested in Mr. Buck's information concerning the cause of the "digesting" of the pin. This has bothered me on a number of transmission lines. I attributed this trouble to the formation of ozone. If it is due to the formation of nitric acid, I am glad to know it. As far as I know, on the particular line on which the Locke iron pins with wooden threads were used, the burning was not serious. The thread was punctured at one point but was in no other way injured. In order to relieve the mechanical strain between the iron pin and the insulator, I think it is quite possible to use a lead thread. Litharge and glycerine have been used to some extent in this country to cement iron pins in porcelain insulators, but lately Portland cement has been used with quite as good results. I understand that one of the largest new transmission lines in Mexico is to be built with iron pins and porcelain insulators. The pins will be cemented in the insulators with Portland cement. Instead of iron poles, iron towers will be used, placed 400 or 500 feet apart.

A Note on Line Insulation for High Voltage.
[communicated by m. h. gerry, jr.]

The maximum practicable limit of pressure on transmission lines has been frequently stated as fixed at a certain voltage, but this limit has as frequently been extended, with good results. At the present time, no considerable difficulty should be experienced with 100,000 volts, and there is no good reason to fix the limit at that figure.

The problems of insulation are becoming better understood, but there is still much to learn. The capacity and the surface effects of line insulators have received but little attention from engineers and many of the failures are due to this fact. The form of the insulator and the material have not, in general, received the proper treatment. A desirable insulator for high-tension is not merely a piece of glass or porcelain arranged to shed rain, and of sufficient thickness to resist puncture.

The materials for construction of insulators are not so limited as assumed in the past. Glass and porcelain have been used almost exclusively, but from the experiments of the writer the material of greatest promise for high-tension insulators is prepared paper. Organic material, such as paper, has great advantage and is well suited for this purpose. Compound insulators in which the petticoats and water-sheds are made of metal, and the core of glass, porcelain, paper or other insulating material, are also feasible.

For moderate tensions, up to perhaps 30,000 volts, insulators having metal tops and outer petticoats are not only perfectly feasible, but are very desirable, and can be made very strong and practically indestructible, and much superior to the common glass or porcelain types now in use. For high voltages, the entire insulator can be made of prepared paper, or of a combination of paper with glass, porcelain or other insulating materials. Insulators on these lines may be designed for almost any desired pressure obtainable with commercial transformers, provided that all the conditions are properly understood in advance.

The writer has tested and experimented with nearly every type of insulator manufactured and with many special forms and constructions, and his conclusions, as stated above, are based on this experience, coupled with that gained from the practical operation of the highest voltage transmission in commercial service to-day.

[Communication after Adjournment by W. N. Smith.]

An important matter that has not been touched upon in this discussion is the design of the pole-top pin, which, on a single three-phase transmission line, is of equal importance with the cross-arm pins. As in other details of line construction a variety

of methods has been followed, of which some are doubtless better than others as regards their mechanical features. In the construction that has come under my observation, either the top of the pole has a hole bored vertically to receive a bolt or the shank of a wooden pin, or else a so-called " ridge iron " has been lag-bolted to the pole top, with the usual wood or porcelain fittings for carrying the insulator. Sometimes an ordinary oak bracket is framed into the top of the pole, the roof of which is shaped to accommodate it.

Without entering into a discussion of the relative merits of these or other methods, it seems to me that there is enough difference between all the methods in vogue to warrant an attempt at standardization. This subject would, therefore, seem to be a proper one for the careful consideration of the Committee on High-Tension Transmission.

[COMMUNICATION AFTER ADJOURNMENT BY J. R. ARMSTRONG.]

Relative to the discussion on " Insulator Pins for High-Tension Transmission Lines," the iron pin seemed to be spoken of favorably by a great many present, but to me this iron pin has one great disadvantage (leaving the difference of coefficients of expansion of glass and iron out of the question)—nearly every pin has a burr on the end, due to the way in which the ordinary pin is manufactured.

Now, there is a tendency to a continual discharge between the line and this burr or sharp point on the other end of the pin. This, after a time, cuts through the glazed finish of the insulator, and consequently causes the breaking down of the insulator.

Also in the same discussion, one of the objections raised to the use of wooden pins was that of the corroding at the ends and sides.

I would just like to raise the question: if nitric acid is formed as was suggested, could not some base be used, which would form a neutral salt with nitric acid, the pin being treated in some way with this base.

[COMMUNICATION AFTER ADJOURNMENT BY F. S. WOODWARD.]

During the discussion relative to the breaking down of insulators and the burning of high-tension insulator pins, one possible cause of the trouble was not stated. It may sometimes be due to the method of fastening the tie-wire to the insulator. In many cases I have known linemen in making what is known as a pigtail tie, after the wire was finally twisted, to bend down the end of this pigtail so that it came in contact with the surface of the insulator at a point near the lower rim; the distance between the edge of the rim on the insulator and the end of the tie, depending, of course, upon the tie's length. This would reduce the amount of creepage surface between the pin and the tie-wire, which partakes of the line potential. In this connection it might be well to state that in some cases spun-yarn, thoroughly saturated in tar or asphalt or in P. & B. paint, makes a good substitute for tie-wire, the coating practically protecting the spun-

yarn against weather effects. It might not, however, be serviceable upon a line under the conditions of voltage as described by Mr. Buck, where the surface of the line wire and of the ties showed signs of reaction due to the formation of nitric acid, which would probably affect the vegetable fibre of the spun yarn in the manner indicated in the case of the thread of the insulator pin. I regret that Mr. Buck did not state the size of the iron wire used on their experimental 75,000 volt line. I recall the paper published in the TRANSACTIONS on the "Dielectric Strength of Air," by Mr. Chas. P. Steinmetz, in which he gave an account of a number of experiments on the sparking distance between sharp points, between spheres of various sizes and cylinders of various sizes. The lower portions of the curves, as I recall, departed more and more from the straight line effect as the voltage was reduced and radius increased. It would be interesting, in this connection, to follow out these experiments and see whether a change in the diameter of the wire (practically being a continuous cylinder) would stop sparking or brush discharge at the desired voltage. For instance, if the wire in Mr. Buck's experiment was a No. 8 and the wire in the second experiment was a No. 1 or a No. 2, if the increased radius would so modify the curve that the brush discharge and the probable formation of nitrogen would be prevented.

As a sequel to the discussion on pins and insulators, it would be a very desirable thing to take up and standardize the cross-arm to which these pins are attached. Also that the distance between wires and the most desirable method of spacing same should be outlined in the report of the Transmission Committee.

COMMUNICATION AFTER ADJOURNMENT BY HENRY FLOY.

Fearing that the remarks of some of the speakers may have left an erroneous impression as to the potential of telephone circuits carried on the poles of high-tension transmission lines, I desire to state that some measurements made by a Weston voltmeter between the conductors of a telephone circuit placed five feet below the conductors of a 25,000 volt overhead circuit and ground, showed the potential to be only from 140 to 160 volts. Similar measurements on a telephone circuit three feet below a 10,000 volt line showed only about 95 volts to ground and, naturally, no difference of potential between the telephone conductors. It seems to me that the voltage of a telephone circuit given as 20,000 by Mr. Thomas cannot be such potential as would be indicated by a voltmeter or such as would cause particular damage, being, I assume, simply static potential.

Referring to the suggestions made as to signaling in case of partial breakdown of the telephone system, it has occurred to me that as a relay to the telephone circuit, a system of wireless telegraphy could be installed without large expense, which might advantageously be used in transmitting signals in case of trouble with the telephone circuit.

DISCUSSION AT MINNEAPOLIS, MINN., APRIL 3, 1903.

The Minnesota Branch held its 11th regular meeting Friday. April 3d, at the Electrical Building at the State University. Six members and 13 visitors attended.

The meeting was devoted to the four papers of the Transmission Committee. The papers were read, and produced considerable discussion. Prof. D. C. Jackson, of Wisconsin State University, and Dean F. S. Jones, of the Engineering Department of Minnesota State University, were present. The opinion of the members regarding the papers and new ideas brought forth were:

1st. That the proposed standardization of pins and pole construction must consider not only the transmission voltage, but particularly such local conditions as mist and dampness at inland lakes and from the ocean, of salt storms, the amount of lightning, etc.

2d. Regarding wooden pins, that trouble from same must be expected in time, say after fifteen years' service, when the pins have weakened mechanically. An iron pin would seem to be more permanent.

3d. That wooden pins should not have a shoulder just above the cross-arm. The use of a shoulder produces additional mechanical strains in the pin at the cross-arm or shoulder not considered in the formula or theoretical basis given by Mr. Mershon. The shoulder was considered a relic from telephone lines and not necessary or advisable where there are heavy mechanical strains.

4th. That in service, the great majority of the insulator failures were mechanical and were due to strains produced by a poor fit between the pin and the insulator. Manufacturers of porcelain and glass insulators in the States produced excellent insulation, but the threads were not of uniform size in each and every insulator, as in those made by foreign manufacturers. The best workmanship is also desired in cutting the iron or wooden threads of the pin.

5th. That transmission lines as a whole—the pole, arm, pins, insulators and power circuits—have many weak links, in a long line. It is advisable where there are two or more companies, possibly competing for the power business of a city, to have connecting circuits and even to operate their lines in parallel. A somewhat similar arrangement is common among steam railways. A competing road gives the use of its tracks to a rival during temporary trouble to roadbed or at a burned-out bridge. A working arrangement of this nature, *i.e.*, to assist each other as far as possible in times of trouble, would help the reputation of power transmissions.

DISCUSSION AT SCHENECTADY, APRIL 7, 1903.

DR. F. A. C. PERRINE:—There is so much in these papers, that it is hard to enter upon a discussion of them. In regard to the paper by Mr. Mershon, I believe that there is one element in the strength of the pin which he has altogether neglected, which however, may possibly be neglected on account of the roofing or rounding of the cross-arm. I refer to the element of strength in the shoulder. The pin is discussed as a beam fixed at one end, and in consequence the ordinary parabolic section of the beam is brought out, because the fibers of the pin are considered to be in tension or compression. Now, as a matter of fact, if the shoulder is made pronounced and firmly fixed on the cross-arm, the pin is very much increased in strength; because there is an element of the stress applied to the end of the pin, which is transmitted parallel to the side of the pin and against the cross-arm.

Mr. Mershon says that usually pins break off at the shank. This is generally the case where pins do not bear on their shoulder in the cross-arm. In some experiments made in the West with a number of pins, I found that if the pins were given a proper shoulder and made to bear in the cross-arm, they did not break at the shank, but broke diagonally from a point about at the end of the thread crossing the pin. The pins that were tested were approximately the same locust pins that were mentioned in the discussion. By giving these pins a proper bearing, the strength was found to be increased from 700 lbs. to 900 or 1,200 lbs., with approximately the same pin.

I notice that the pins designed by Mr. Mershon correspond very closely to the pin in Fig. 1 in Mr. Chesney's paper. Furthermore, I see that the pin in Fig. 1 in Mr. Chesney's paper is not given a bearing in the cross-arm, as the shoulder is filleted so that it does not come down to a solid bearing. The other pin in Fig. 2 is given a solid bearing, and this pin is very much stouter than the pin in Mr. Mershon's paper or the pin in Fig. 1. As you will notice, these pins are both for the same insulator. The pin in Fig. 1 is the pin used on the Standard Company's lines and in Fig. 2 the pin used on the Bay Counties lines. Mr. Hancock of the Bay Counties Company designed this pin after testing a number of pins and insulators. He found that the pin in Fig. 1 would almost invariably break before the insulator; that the pin in Fig. 2 would practically never break before the insulator, this pin havin, practically the same strength as the insulator. The material is eucalyptus. Since the discussion, Mr. Hancock has reported that the strength of this eucalyptus pin compared with a steel wagon-axle. The axle was broken at a strain that would not break the insulator, although the wood pin was of approximately the same strength as the insulator.

The observation made in the discussion that Mr. Mershon's pin is based on a uniform stress applied to the insulator, and that

this is not a reasonable specification for the standard pin, is a point that is very well taken. With lines such as are proposed now, with spans of five or six hundred feet, the transverse stress on a wire from one-half to three-quarters of an inch in diameter, will be in excess of 600 lbs. With oak or locust, as specified by Mr. Mershon, the pin will not have a strength much in excess of 600 lbs. With ecualyptus, it would have a greater strength, eucalyptus having approximately the strength of good hickory. In such spans of five or six hundred feet it would be necessary to install more than one of Mr. Mershon's pins to stand the strain from heavy cables.

In regard to the testing of glass insulators, so far as I am aware,having had experience with a good many thousands of glass insulators, the puncture of glass insulators by reason of breakage after the insulator had been inspected visually and tapped with a mallet, is very unimportant. The point that Mr. Blackwell makes of glass insulators breaking down, due to lack of annealing is, on the contrary, an exceedingly important one. One of the lines in California installed a type of glass insulator that had been well tried, but apparently it received a batch of unannealed insulators, for before the end of the year a large number of their insulators separated and broke down; the head of the insulator cracked off and let the wires drop. Such occurrences with glass insulators, are far more important and more likely to happen than punctures. A glass that will puncture at all, I believe to be a glass that is so bad that you could see the defects. No insulator should be installed which has a bubble between the wire and the pin, because these bubbles are vacuums, and you might as well have just so much metal in the insulator.

Mr. Lincoln's paper, is I think, the first approaching a complete discussion of the telephone line transposition problem, and it is so complete that I cannot sit down without commending it, without saying that in my belief it contains the elements of the entire solution of this very important and difficult problem. Had this paper been printed four years ago, I believe that I know of more than one man's life that would have been saved by it. A very sad accident happened about a year ago: A patrolman starting out to work, went to the closed telephone box to report. In connecting this telephone to the line, he was killed. I believe the power line was grounded, but not to the telephone line. Since that, the company has observed the rule of seeing that the operator is insulated as well as the line.

The question of potential to earth is the only thing that Mr. Lincoln has not given an absolute statement of, and I am inclined to think that that is because there is something in it that we don't yet know. Mr. Lincoln writes of the difference of potential, but says that that represents so small a current as to be inappreciable If the surface of the condenser that is produced by the power line

and the telephone line and the condenser of the telephone line and the earth is calculated, where the line is one or two hundred miles long, the amount of current that is transmitted will not be by any means inappreciable, and will be enough to give a great deal of trouble. This is the only criticism that I would have to offer to this most excellent paper of Mr. Lincoln's.

Discussion at Pittsburg, April 9, 1903.

Programme.

The meeting was called to order by Chairman P. M. Lincoln.

1. Introductory Remarks.—President C. F. Scott.
2. "Mechanical Specifications for Proposed Standard Insulator Pin," by Ralph D. Mershon, read by W. K. Dunlap.
3. "The Testing of Insulators," by F. O. Blackwell, read by C. E. Skinner.
4. "Transposition and Relative Location of Power and Telephone Wires, by P. M. Lincoln.
5. "Burning of Wooden Pins on High-Tension Transmission Lines," by C. C. Chesney, read by E. M. Tingley.

The discussion was participated in by C. E. Skinner, S. P. Grace, P. M. Lincoln, H. Etheridge, C. W. Rice, Mr. Bedell, P. H. Thomas, B. Frankenfield, J. S. Peck and President C. F. Scott.

Mr. Skinner:—I have always been under the impression that for glass insulators a potash glass would give better results than a lead glass. This impression has not been thoroughly proved by test. Mr. Blackwell says that the striking distance of a given e.m.f. is greater at high altitudes than at low altitudes. If the striking distance is to be used by the Institute as a measure of the e.m.f., some figures should be obtained showing the variation of striking distances with the variation in the height of the barometer.

In early high-tension work the question of surface leakage over the insulator was considered of very great importance, and many of the earlier designs of insulators included an oil cup underneath to give a higher surface resistance. As far as I am aware, this construction has not been used on any of the long-distance transmission lines in the United States, and later practice has proved that such a device is entirely unnecessary. It is objectionable because it is soon filled with foreign substances and defeats the object for which it was designed.

The method of regulating the voltage of the testing transformer should receive consideration. There are three methods which have been followed, viz: first, by varying the field of the generator; secondly, by the use of a resistance in series with the low-tension side of the testing transformer; thirdly, by varying the voltage on the low-tension side of the transformer by means of a regulator dial connected to a suitable regulating transformer with a number of taps brought out from its secondary winding.

The first method can be used only where a generator is provided exclusively for this work. In the second method a water rheostat is usually employed. This gives a very smooth variation in e.m.f., and while unwieldy and requiring constant attention during the test, it is capable of giving very good results. The third method requires that the voltage on the high-tension side be changed by comparatively small steps, which may be done with proper regulating dials without opening the circuit. Steps

even as great as 5 per cent. are not considered particularly harmful in the testing of insulators.

I am pleased to be able to show you an exhibit of insulators intended for high-tension work. This exhibit is not complete by any means, but shows a number of types which are in use at the present time. Most of these insulators have been given a test which may be briefly described as follows: the insulators were placed on the standard-size pin, the pin being wrapped with tin-

foil. A photograph of the insulators (Fig. 1) as they appeared on the testing rack after a snow storm is submitted as part of this discussion. The test was made by applying the high potential from a testing transformer, the voltage of which was regulated by means of a regulator dial giving very small steps. The testing voltage was applied between a " tie " made in the ordinary manner and the tin-foil coating of the pin and the test was made under different weather conditions. The breakdown test was repeated at intervals for a period of some months, beginning about the middle of February and ending about the first of July.

In no instance did a breakdown occur through the insulator

itself, the break in every case being over the surface. The maximum testing voltage available was approximately 90,000 volts. In some instances, when the insulator was dry, no breakdown over the surface could be obtained. The following are the results of tests on certain characteristic insulators, as shown in the accompanying photographs. (Fig. 2 and Fig. 3).

No. 1—Porcelain, brown glaze:

Diameter at base	10″
Height	8¾″
Surface distance from wire to pin	22¾″
Shortest breaking distance	12″

When dry and clean, stood	91,000	volts.
During heavy, dry-snow storm, stood	90,000	"
During moderate rain storm, broke down at	86,400	"
When covered with ice and snow, broke down at	52,200	"
When dry, stood for ½ hr.	71,500	"

FIG. 1.

During the last test the snow was piled on the cross-arm almost to the lower petticoat.

No. 2—Porcelain, brown glaze:

Diameter at base	7½″
Height	6¾″
Surface distance from wire to pin	13½″
Shortest breaking distance	9⅝″

When dry and clean, stood	92,000	volts.
During dry-snow storm, broke down at	87,300	"
Covered with wet snow, broke down at	62,100	"
During moderate rain storm, broke down at	68,400	"
When dry, stood for ½ hour	66,000	"

No. 3—Porcelain, brown glaze:

Diameter at base	6¾″
Height	4⅞″
Surface distance from wire to pin	13″
Shortest breaking distance	7¼″

When dry and clean, stood ....91,000 volts.
During dry-snow storm, broke down at..... ...78,750 "
During moderate rain storm, broke down at ....48,600 "
Covered with wet snow, broke down at...........54,000 "
When dry, stood for ½ hour ....64,400 "

No. 4—Porcelain, brown glaze:
Diameter at base .... 6½"
Height .... 4¾"
Surface distance from wire to pin .... 8"
Shortest breaking distance............................ 6⅝"

When dry and clean, broke down at ....73,800 volts.
During dry-snow storm, broke down at.........78,750 "
During moderate rain storm, broke down at ....53,400 "
When covered with wet snow, broke down at ...52,350 "
When dry, stood for ½ hour ....55,000 "

FIG. 2.

No. 5—Porcelain, white glaze:
Diameter at base .... 6"
Height .... 4"
Surface distance from wire to pin.................. 11¼"
Shortest breaking distance .... 6¼"

When dry and clean, broke down at ....74,700 volts.
During dry-snow storm, broke down at.........70,200 "
During moderate rain storm, broke down at ....70,400 "
When covered with wet snow, broke down at ...42,800 "
When dry, stood for ½ hour ....52,500 "

No. 7—Glass:
Diameter at base .... 7"
Height .... 6"
Surface distance from wire to pin.................. 15½"
Shortest breaking distance......................... 7⅞"

When dry and clean, broke down at	74,700 volts
During dry-snow storm, broke down at	73,800 "
During moderate rain storm, broke down at	52,800 "
When covered with wet snow, broke down at	51,100 "
When dry, stood for ½ hour	55,000 "

No.8—Glass:

Diameter at base	7½"
Height	5½"
Surface distance from wire to pin	12"
Shortest breaking distance	7⅝"

When dry and clean, stood	91,800 volts.
During dry-snow storm, broke down at	87,300 "
During moderate rain storm, broke down at	62,700 "
When covered with wet snow, broke down at	58,800 "
When dry, stood for ½ hour	63,000 "

FIG. 3.

After the insulators had been up for some months and were well coated with dirt and soot they were given a time test on a dry day. The time test was made by applying ¾ of the maximum test voltage for ½ hour. The figures are given under the last heading in each set of tests. All the insulators stood this test without any evidence of trouble, except a considerable static discharge over some of those with the thinner sections.

I think that the burning of pins is caused in many cases by the static discharges which appear at the wire and at the pin. If the material can be made thick enough, so that these discharges will not appear, the burning of the pins will probably be decreased to a very considerable extent. I think the final solution of the pin-burning question would be to discard the wooden pin altogether and substitute a metal pin properly cushioned to take undue local strains off the insulator itself.

Mr. Grace called attention to the trouble which the telephone ompanies have had from electrostatic effects. As fast as one difficulty has been overcome another is encountered, to overcome which new methods must be devised.

The system of transposing wires in order to overcome the induc-

tive effects of one circuit upon another was devised by the telephone engineers and first used on the long-distance circuit between New York and Philadelphia.

The necessity of keeping telephone circuits in absolute balance was mentioned and a number of instances were given where an extremely small amount of unbalancing was sufficient to produce serious disturbances.

Mr. Grace said that Mr. Lincoln's paper treated only of telephone circuits upon the same poles with the power circuit, whereas in commercial telephone service there were many thousands of circuits and it is manifestly impossible to insulate them to so high a degree as where there is but a single telephone circuit. He thought that representatives from the telegraph, telephone, and power-transmission companies should convene and devise suitable means for crossing the different lines where it is necessary.

Mr. Frankenfield commented on the effect of grounding the neutral point of a transmission system. He also commented on the burning of insulator pins.

Mr. Bedell recounted his experiences while testing insulators. His general conclusions were that the question of dielectric strength of glass and porcelain had been satisfactorily settled, as insulators almost never broke through the dielectric but over the surface.

Mr. Lincoln:—One interesting statement made by Mr. Grace was that the arc circuits of the "tub system," so-called, is one of the hardest things the telephone people have to contend with. This sustains one of the arguments made in my discussion—that the static induction gives more trouble than the electromagnetic. The conductor in such an arc system is apt to be at a considerable difference of potential from the earth, and usually in the arc circuit the equal and opposite potential is not present to neutralize its effect as is the case with a statically balanced transmission line. I should imagine the arc circuit would be harder to contend with, though its potential is not so high as that of the usual accompanying transmission line. I should like to have Mr. Grace explain what he calls a retardation coil.

Mr. Grace:—It is an electric choke-coil and we speak of it as a retardation coil.

Mr. Etheridge:—I wish to refer particularly to the necessity of studying every detail of a transmission line, with the view of applying the latest and best possible forms of construction to insure the stability of the medium between the step-up and the distant step-down transformer.

Estimates are carefully prepared and the best engineering skill applied to the erection of central plants and substations, but the transmission line, which is subjected to the worst possible mechanical and electrical strains and conditions, is, generally speaking, the least considered and provided for.

The building of a transmission line is purely a mechanical problem, and must receive as much care and skill as the remainder of the system, if stability of action—which is the keynote of engineering success—is to characterize its operation.

The average transmission line suffers from comparison with the modern power house and substation equipment, and as the system is strongest only at its weakest point greater care and skill must be applied to that part of the system which is found outside the buildings, where the most adverse mechanical and electrical conditions are encountered.

Our worst experience in the operation of transmission lines has been due to mechanical weakness of some of the details of the line; particularly wooden pins and faulty mechanical design of some of the insulators. The angles and guys have also given us trouble on account of their inadequacy for the heavy strains put upon them. I can safely say that electrical troubles of our line have been entirely absent. To overcome the mechanical troubles of pins and insulators, we were compelled to design and adopt a form of pin and insulator a sample of which you will find on exhibition here this evening, and in which the greatest mechanical strength and other features are embodied.

Having solved the question of weak pins and insulators, we next turned our attention to the angles of our line and to proper guying with the result of developing a rigid and successful form of construction. In these angles we have adopted poles of 13″ and 14″ tops, 4″×5″ double oak cross-arms with ¾″ ring bolts and washers. The braces are ⅜″×1½″ and 30″ long, bolted with ½″×⅝″ bolts and washers in cross-arms and through the poles, respectively. The cross-arms are bolted together with ⅝″ bolts and washers with the usual making-up piece between them. The pin-holes in the cross-arms are 1½″ diameter, thereby maintaining the strength of the arm. Great care is also exercised in placing the arms diagonally across the angle so as equally to distribute the strain on each pin and insulator.

The " wet-rot " of our poles at the butt received our next attention, as it became evident to us that in seven to ten years our entire pole line would have to be rebuilt; a feat fraught with great danger, expense, and interruption in our service, if it did not threaten absolute shut-down.

I developed and adopted a remedy against this " wet-rot " of our poles. This consisted in cementing about one-third of the pole flush to and extending about 3″ above the ground line, and then placing a fillet of pitch, asphaltum, or some such moisture-proof material to a depth of about 8″ between the pole and cement of the ground-line, so as to separate or seal the pole from contact with the moisture in the earth at the ground-line. This very effectually prevents " wet-rot " of wooden poles and oxidation of steel poles at the ground-line. The additional expense of preparing and treating our poles in this manner is very trifling compared with the great expense of replacing them.

Mr. Scott has well said that " development of detail in electrical machinery has made possible very reliable forms of apparatus," and the same reasoning and skill must be applied to our transmission line before the ideal electrical transmission will be attained.

At the request of Mr. Lincoln I will explain the features of the pin and insulator which it was my pleasure to develop. It consists of a malleable iron tube $1\frac{7}{16}''$ outside diameter and $1\frac{1}{8}''$ inside diameter. On the outside of this tube-pin is cast a shoulder on which it rests when placed in the cross-arm. To lock this tube-pin to the cross-arm a flat high-carbon steel spring—on each end of which if formed a gib—is driven through the pin until the bottom end springs out over the bottom end of the pin and cross-arm.

The insulator, which has a plain hole to receive the pin, and a recess at the bottom of the hole to receive the top gib of the spring, is then forced down over the pin until the top gib springs out into the recess in the insulator. This combination very securely locks the insulator to the pin and the pin to the cross-arm; to unlock, place a screw-driver between the lower gib and the pin, force the gib back and drive the spring out through the pin again.

The features of this form of pin and insulator are:

(1) Simplicity and durability.

(2) The presenting of a plain surface, so as equally to distribute the wire pressure between the contact or bearing surface of the pin and insulator.

(3) Secure locking to the cross-arm and ease of removal therefrom.

(4) Freedom of insulator to turn in either direction on pin and act as a sheave to the wire when used in angles.

(5) Looseness of the insulator on the pin, avoiding the breaking of insulators from expansion or contraction.

(6) Locking the insulator to the pin and cross-arm, yet preserving looseness and freedom on the pin.

(7) The placing of the wire groove in insulator so as to relieve the insulator from any wire leverage and any stress other than one tending to crush the glass or porcelain, etc.

Our telephone system is erected on the same poles and is bracketed about 5 feet below the lower cross-arm. These lines are absolutely quiet; the electromagnetic and electrostatic influence being overcome by using twisted pairs of wires.

(For illustrations of pins described by Mr. Etheridge, see New York Discussion, pages 26 to 57.)

Mr. Thomas:—As Mr. Etheridge has said, the greatest practical difficulty in the operation of high-tension transmission lines arises from mechanical defects rather than electrical ones. Broken pins, broken cross-arms, broken insulators and injuries to the line from external causes vastly outnumber the electrical failures. As is easily seen, the pin is the weakest mechanical link

of the system and when of wood of good insulating quality it is liable to be weak. I wish to call your attention to a plant installing at Mexico, which marks an improvement in pole-line construction from a mechanical point of view. Five hundred foot spans are used, which is approximately five times the length of span usually employed elsewhere, and instead of the usual wooden poles there are built-up steel towers. The cross-arms and pins, I understand, are of steel, the insulators of porcelain. This construction if well designed assures excellent mechanical qualities, and should be watched with great interest. On account of the small number of poles a much larger pin can be economically used for each one.

Ground wires, such as Mr. Lincoln has recommended for protecting the telephone circuit on a transmission line, might be used on telephone trunk lines, parallelling transmission lines, close to the telephone line but between it and the power line. It is probable that a very great reduction of the static induction from the high-tension would be obtained by the use of even a few grounded wires as a screen. I make this suggestion to Mr. Grace.

The question of lightning arresters for telephones, and the fact that they are ordinarily adjusted to discharge at about 300 volts, suggests the mention of a point in the operation on the telephone lines and power circuits by which in some cases the service has been very much improved. In a good many power transmission systems where the standard telephone arrester is used on the telephone circuit, it has been found that there is at almost all times a sufficient unbalance of the high-tension voltage so that a frequent discharge to ground occurs over these arresters, the result being a leaky line and more or less continuous rattle of the telephone. The construction of an air gap in place of the lightning arrester very much reduces the number of such discharges to ground and entirely prevents the high resistance leak which usually occurs in a telephone arrester. The result is a great improvement in the speech.

Some of the telphone engineers here have referred to the problem of making satisfactory cross-overs between two lines. From their point of view the transmission line is a telephone line. The problem is broader, however, and should include the crossing of two high-tension lines. The National Board of Fire Underwriters has recently adopted recommendations as to methods of such cross-overs. They suggest three methods, but preference is expressed for crossing by means of a pole common to the two lines. This pole should, of course, have extra strength and extra height, the highest tension line being carried at the top. Extra long cross-arms are used and the difference in the height of the poles of the upper and lower lines will ordinarily prevent anything which falls from the upper wire to the ground from touching the lower wires. To prevent a wire breaking at the farther end of one of the adjacent spans of the higher line from falling against the lower line, a guard wire mounted on the line, prefer-

ably insulated, should be installed outside of the extreme wire of the lower line.

A wooden pin is burned by leakage current because either its resistance is too high to transmit the current without excessive heating, or because its insulation is too low to prevent the leakage. In most cases either a better or a worse pin would not be injured. A comparatively few per cent. improvement of the pin would in many cases be sufficient to prevent destructive heating. Therefore, the method used by Mr. Gerry for protecting the pin which has been put in first-class condition, from moisture and dirt, by means of a sleeve, is an excellent one, since it will certainly give a considerable protection to the pin and render it oftentimes safe where an unprotected pin will conduct enough to become charred. Mr. Gerry's freedom from trouble from burned pin referred to by Mr. Skinner is probably due to the fact that his pins are protected by glass sleeves, but also it must be admitted that his line is yet young and the climatic conditions are not severe. San Francisco is probably one of the hardest places in the country on pins and I think no wooden pins would be able to stand indefinitely there without burning.

Since the difficulty of operating a telephone line on an unbalanced high-tension power line results from the tendency for a high-potential to ground—equally on both telephone wires. provided the telephone line be transposed—it may be possible to solve the difficulty by insulating the telephone line highly and allowing it to assume its neutral potential, and transmitting the speech through a raising and lowering transformer at either end. The low-tension windings of these transformers may then be grounded, and with good insulation between the high and low-tension windings the operation may be made very secure.

I would like to ask Mr. Grace whether it is feasible to use such a transformer for transmitting telephonic speech.

The same sort of result might be attained by the use of condensers, two in series with middle grounded, connected between the wires of the insulated telephone line, the telephone receiver or transmitter being connected between the ground plates of the two condensers. For this purpose it would probably be necessary to use a double winding, either on telephone-spool or choke-coil, so that the charging current to the condensers would have its effect on the telephone circuit neutralized.

Mr. Grace:—The use of the transformer, as suggested by Mr. Thomas, is feasible.

Mr. Peck:—In his paper on the testing of insulators, Mr. Blackwell says: "There should be but one transformer used to step up to the highest potential required and its reactance should be as low as possible. A number of transformers in series is particularly bad, as it gives poor regulation and leads to great uncertainty as to the actual potential to which an insulator is being subjected."

In the discussion at New York, Mr. Mershon called attention to

the advantages obtained by the use of a number of transformers in series for obtaining a high voltage, saying that it was possible to obtain such a series having a good regulation; and great point in its favor was that in case of accident to one transformer of a series, the remaining transformers could be used to deliver a some what lower potential.

There is an idea more or less generally prevalent that it is possible to obtain without danger a high voltage by connecting in series a number of transformers wound and insulated for a low voltage, as long as cases are insulated from each other and from the ground. Fig. 1 shows such an arrangement, where three 10,000 volt transformers are connected with high-tension winding in series for giving 30,000 volts.

It will be at once seen that there is a strain of 30,000 volts at the two points (A) and (B). The normal strain for one transformer is 10,000 volts, so that the outside transformers of the series are subjected to three times normal voltage strain be-

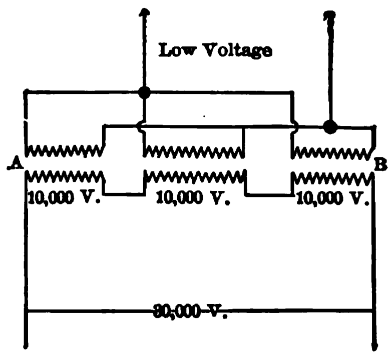


Fig. 1.

tween primary and secondary windings. If there were ten 10,000 volt transformers connected in series for 100,000 volts, the strain across the outer transformers of the series would be 100,000 volts, ten times normal.

In the operation of a number of transformers in series for obtaining a high voltage, there are much more severe internal strains introduced than where the transformers are used for a low voltage. This strain occurs between turns and layers and comes principally on the outside coils of the outside transformers of the series. In designing transformers for connecting in series it is therefore necessary to insulate each transformer not only between high-tension and low-tension windings, but between turns and layers of each winding, in the same manner that would be required were the transformers to furnish alone the full voltage of the series.

On account of the large amount of insulating material demanded between high-tension and low-tension windings, it is

extremely difficult to make these transformers with good regulation on inductive loads.

The cost of small transformers for very high-voltage work is, within certain limits, almost independent of the capacity; so the difference in cost between one transformer of the series and a single transformer wound for the total capacity would be very small.

It is true that the outer transformers of a series may be more heavily insulated than the others, making a reduction in cost on the inside transformers, but this affects the interchangeability of the transformers and the extra cost of manufacturing transformers which differ slightly from each other will probably more than counterbalance the saving in insulation.

The question of a spare unit is undoubtedly of importance, but I believe that in general it will be cheaper to purchase two transformers, each wound for the full testing voltage, than to buy a large number of transformers which are to be connected in series for giving the desired voltage. Where two transformers, each wound for the full testing voltage, are purchased, one will of course be held as a spare and may be used as a voltmeter transformer for obtaining the exact voltage applied to the apparatus on test.

When a number of transformers are in series, the voltage measured across the high-tension winding of one transformer will not be an accurate indication of the total voltage on the series.

Mr. Rice called attention to the importance of uninterrupted service and to time tests on insulators. He predicted that the highest transmission voltage would very soon be generated directly by the dynamos, without the use of raising transformers. He also thought that the shoulder on the proposed pin was too small as the side strain would cause the shoulder to cut into the cross-arm, thus enlarging the hole so that the pin would finally pull out.

Mr. Scott:—I recall my first experiments on the relation between the telephone and a high voltage. In the laboratory a telephone was connected in circuit between a high-tension terminal and a short length of wire. It gave a vigorous sound which was attributed to the flow of current to the wire acting as a condenser. The wire was disconnected and the telephone still responded. The wire was then disconnected from the telephone circuit and was connected to the insulated magnet. The telephone still responded.

Some measurements upon the potential generated on an insulated wire not far from a high-tension circuit which were made by Mr. Tingley, who is here this evening, are reported in a paper on High-Voltage Transmission presented before the Institute by me in 1898. These experiments show that a single insulated wire not far from a high-tension wire may have a potential sufficient to cause a spark to jump over a considerable gap to the earth.

I had an opportunity a few years ago to inspect the burning of pins and cross-arms on a 10,000 volt transmission line on the Pacific Coast, which ran for some distance close to the shore. Large holes were burned in some of the cross-arms and poles. The burning was particularly apt to occur at the ends of the iron braces between the pole and the cross-arm. There was little doubt but that particles of sea water as " fog " were carried by the wind and deposited salt upon the poles and cross-arms. I understand that this difficulty has been avoided by placing wooden frames over the insulators on the ocean side.

Mr. I. Sternefeld of Mexico has called my attention to the deterioration of copper wire due to the salt air from the ocean. He says that he has found a satisfactory remedy in an insulated coating consisting simply of cotton dipped in a solution of minium and linseed oil.

It is notable that *megohms*, which used to be considered of prime importance in the testing of electrical apparatus, has not been mentioned in the discussion this evening. The problem in line construction is primarily to prevent disruptive and disastrous breakdown. It is not the *ohms* but the *volts* which are of first importance.

The collection of insulators before us this evening, containing some early forms as well as recent ones, small insulators as well as big ones, indicates the evolution which has taken place in insulator construction, both in materials and form during the last ten years.

The insulator problem, as presented in the discussion this evening, is at the present time primarily a mechanical problem. Electrically, it is partly one of materials and partly one of geometry. There is an intimate relation between geometry and voltage in insulator design. There is also the commercial problem.

High-tension tests upon apparatus, particularly transformers, is an important matter. The conditions prevailing at high voltages are to my mind different from those at lower voltages. Low-voltage apparatus may probably be tested at several times its operating pressure. The margin between the normal pressure and the test will be but a few thousand volts. If, however, transformers for 40,000 or 50,000 volts be tested at double pressure the margin is also 40,000 or 50,000 volts. The purpose of making a test of this kind is to determine first whether the design is satisfactory in giving sufficient surface distance and the like, and second to detect flaws in material or in construction. A momentary or short test is in general sufficient to determine these points. The prolonged test may have a deleterious effect upon the insulating materials by weakening them. The test may result in a breakdown due to conditions entirely abnormal to service. On the other hand, although there may be no breakdown the materials may be left in a condition weaker than tney would have been if the test had not been prolonged.

MR. BUDD FRANKENFIELD:—Speaking of the dependence of transmission systems on the telephone in time of emergency, recalls an incident that came under my observation on the coast. It belongs in the category with the somewhat disastrous accidents that sometimes occur when too great reliance is placed on automatic devices.

A fire occurred in a city that received power from a long-distance transmission system. The fire caused havoc in the secondary network, and the substation attendant pulled all his switches in the emergency, without first notifying the power house. At the power house the governors happened to be off duty and the impulse wheels took on speed. Instead of taking recourse to the "Armstrong system" and shutting down the plant as he might have done, the power station attendant ran to his telephone booth to call up the substation.

He never got into communication; for there was a crash which brought him out of the booth to gaze in open-eyed wonder at the roof above—the fly wheel had gone soaring heavenward and it left a great hole in its wake. Here is an instance where it had become so natural to use the telephone in every emergency that, what is ordinarily a blessing, proved a source of danger. The moral is to use "horse sense" even when surrounded by modern conveniences.

In regard to the suggestion that the ground be brought near the telephone line by means of an earthed conductor placed in proximity, I would like to recall the fact that grounding the neutral of a Y. connected transformer system has this effect, as stated in the paper, that the telephone line tends to assume the potential of the neutral point of the transmission system; and the grounding of this point will virtually bring the telephone line to the potential of the earth. It seems to me a method worthy of careful consideration.

It has been suggested that by using an iron insulator pin burning would be avoided because of the low resistance of the pin; and it has been urged in opposition, that the wooden pin has some give to it and is less likely to break insulators. Why not combine all the good qualities in one pin, a wooden pin with a metallic coating? Cover it with foil, paint it with a metallic paint, electroplate it if need be—do anything to make it a good conductor. A study of the Redlands type of pin, which is said to have shown deterioration only at the wooden thread and which is said to have caused no burning of cross-arms, is an indication of the result to be expected with a metal-coated pin—no burning at all.

A paper presented at the 20th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, New York, July 1, 1903.

METHODS OF BRINGING HIGH-TENSION CONDUCTORS INTO BUILDINGS.

BY C. E. SKINNER.

One of the points in the design of high-tension transmission lines which seems not to have received general attention is the method of supporting and insulating the conductors which connect the transmission circuit with the apparatus in the generating stations and substations. Each engineer follows the plan which seems to him best for his particular set of conditions. In some cases the line is brought through a hole in the wall; in others through an elaborate system of tubes placed in the wall; in others, through a piece of insulating material of some kind set in the wall; in others, the line is entered through an elaborate tower built for the purpose on the top of the building; in still others, it is taken directly through the roof of the building.

It is manifestly impossible to prescribe any fixed method for all voltages and all locations, as the requirements of each plant are varied by the local conditions, but much would be gained if the general requirements were outlined in such a way that designers of buildings and designers of plants could follow some general and accepted scheme which is known to be satisfactory for any given set of conditions. It is the purpose of this paper to discuss the general requirements rather than to give specific designs, although specific methods must necessarily be referred to in this discussion.

The method to be followed will depend on the following conditions:

(1) The voltage of the transmission circuit.

(2) The climate in which the plant is operated.

(3) The size of the high-tension conductor.

(4) The kind and height of building used.

(5) The conditions of approach to the building and the location of the apparatus in the building to which the high-tension line is connected.

The requirements which must be met are:

(*a*) *The Maintenance of Proper Insulation of the Circuit.*—To maintain proper insulation, it is necessary either to allow sufficient open space about the wire to prevent any possibility of the current striking across to the walls or surrounding material; or some insulating medium, such as a tube, must be applied to the wire to give the proper insulation.

(*b*) *The Prevention of the Entrance of Rain, Snow, Cold Air and Dust.*—The entrance of moisture, snow, and dust, should be prevented both on account of damage to the contents of the building, and on account of the weakening of the insulation at the point of entrance. In most climates it is necessary that all openings be closed for at least a portion of the year.

(*c*) *The Proper Mechanical Fastening of the Line Wire.*—The end-strain of the line must be taken up, and it is often convenient to combine the plans for taking up this strain with those for entering the building. This is particularly true where the transmission conductors are very large. It is also necessary to hold the wire in a fixed position where it passes through the opening into the building. This requires a more rigid line construction than is necessary away from the building.

(*d*) *Reliability and Simplicity of Construction.*—It is self-evident that the construction must be such that it will be reliable under all circumstances. There are usually a sufficient number of troubles on high-tension transmission lines due to circumstances beyond the control of the engineer, without introducing any extra risk at the point where the wire enters the building. Usually, as in most other work, the simplest form of construction will be found the most reliable.

In general, wires are best brought through the walls of the building. The simplest form of construction consists merely of an opening in the wall sufficiently large to allow the proper air insulation between the wire and the wall, this opening being suitably protected from rain either by means of a large pipe set in the wall, sloping outward, or by a sufficint extension of the roof above, or both. The requirements of this form of construction are that the wire be a sufficient distance from the pipe, so that there will be no possibility of striking across under any

conditions. The pipe should always be considered as "ground," regardless of the construction of the building. The cross-arms holding the wire inside and outside of the building should be sufficiently near and so braced that the wire will remain central in the pipe. This construction can be used to advantage only in dry, warm climates.

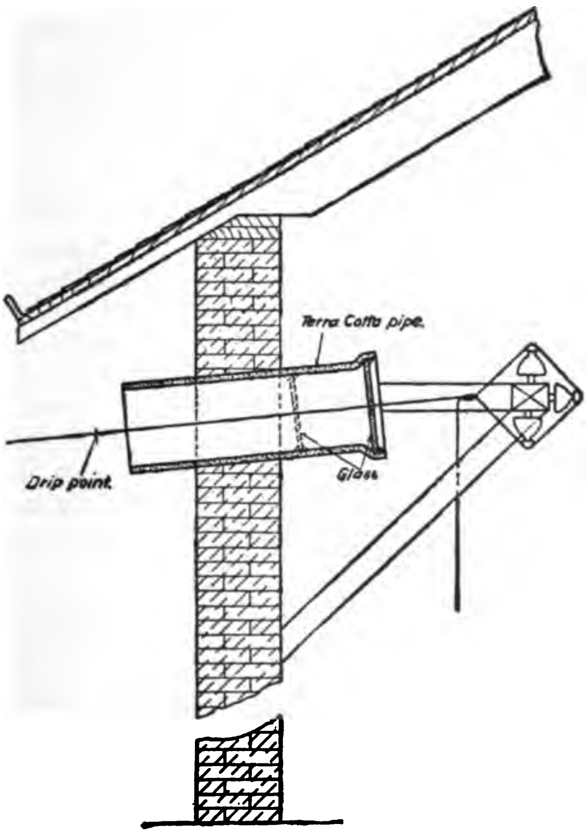


FIG. 1.

In most climates provision must be made for keeping out rain, snow, etc. With potentials of 15,000 volts or lower a disc of glass or other fireproof insulating material placed over the wire at the inner end of the pipe will usually accomplish this purpose. In this case the tube must be sufficiently large so that the surface insulation over the insulating disc used will be ample to prevent trouble under the worst conditions which may occur. When there is any danger of condensation of moisture due to differences

of temperature inside and outside of the building, two discs a little distance apart should be used. These discs may be cut so as to be placed in the pipe itself, or they may be cushioned and simply swung on the wire, lying against the ends of the pipe. The surface insulation of the discs used should never be less than that of the line insulators, and as they will usually be less advantageously placed than the insulators, extra distance should be allowed, if possible.

With potentials above 15,000 volts, this form of construction becomes unsuitable on account of the large size of opening required to give the necessary insulation distance over the discs. This may be true even with potentials below 15,000 volts under very adverse conditions. For the higher voltages, a long insulating tube of small diameter and very heavy wall may be placed over the wire and passed through a slab of insulation set in the wall of the building, the whole being protected from driving rain by an extension of the roof. The insulating tube should slope outward in all cases. Some form of drip point should be provided on the wire just outside the end of the tube. The insulation slab holding the tube should be large enough to prevent actual breakdown even though the tube is broken. Both tube and slab should be of fireproof material. This form of construction has been successfully used for potentials as high as 50,000 to 60,000 volts. The chief difficulty is in securing the proper insulating tubes. Glass and porcelain are electrically the best materials for the purpose, but when these are used it is usually necessary, on account of their lack of mechanical strength, to take up the end strain outside of the building by a suitably guyed pole.

The tower-construction may be necessary where the building is low, and the line wires must be carried at a considerable elevation in the immediate neighborhood of the building. It is generally very cumbersome and unsightly, and the bringing of the wires through the side of the tower presents the same problem as bringing them through the side of the building.

The bringing of the wires directly through the roof of the building, while possible, requires that extra precautions be taken to secure sufficient insulation and to keep out all moisture. This method, however well carried out, will probably constitute a danger point in the system.

In general no combustible material should be used near the line wire, even when separated from it by insulating material

sufficient to withstand the strain. Leakage or brush discharge is liable to cause burning sooner or later, and such burning is more serious at the building than the burning of a pin or cross-arm on the line.

The accompanying illustrations, Figs. 1 and 2, are intended to show diagrammatically the two general plans recommended in this paper. Both plans, practically as shown, are in successful use

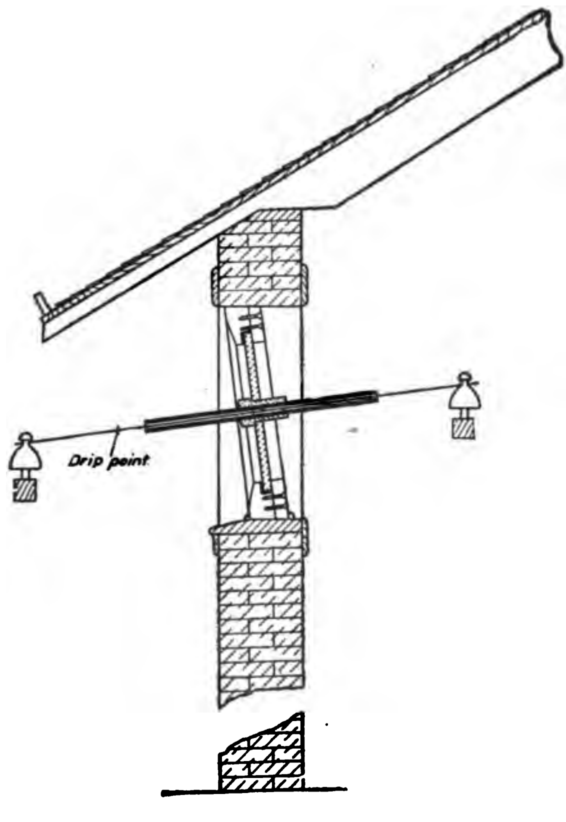


FIG. 2.

by important transmission plants. It is expected that each engineer will find it necessary to make changes in details to suit his particular case, but it is believed that the plans proposed may be made effective for any transmission circuit.

The method of bringing high-tension wires into buildings should be carefully considered at the time the building is designed and proper provision made. It often happens that this point

is given no consideration whatever, and the result is an unsightly and unsuitable arrangement made after the completion of the building and at an increased expense.

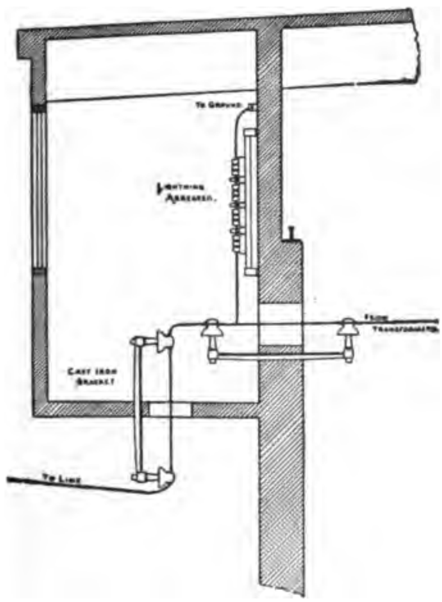
It is hoped that those having practical experience with the design and construction of this particular feature of the transmission line will take an active part in the discussion of this paper, and that by this means the INSTITUTE may be able to furnish general recommendations covering this subject.

DISCUSSION OF MR. SKINNER'S PAPER.

MR. SKINNER:—I have here several communications which I will read.

MR. HENRY FLOY:—Because of its simplicity and reliability, the writer believes there is nothing quite equal to a plain but generous hole in the wall through which the wire rigidly supported, may pass. This form of construction modified as hereafter shown, is applicable to any voltage, and almost any climate.

I consider that the use of glass plates, as suggested by Mr. Skinner in Fig. I., or conductors insulated for a portion of their length as in Plan II., are more or less objectionable because of the constant menace of leakage and grounding of the system, through the wall of the building. The accumulation of dust or



moisture on the glass plates, or the deterioration of rubber or paper insulation due to exposure and weather will sooner or later end in a shut-down; glass tubes and plates are always breaking and never make a really good mechanical job.

If the station is provided with an overhead traveling crane, it will usually be found more convenient to bring the wires into the building through one of the walls rather than into a tower.

Having tried several different methods, none of which were wholly satisfactory, the writer devised the scheme shown in the accompanying sketch, which explains itself. This form of construction has been successfully used in a concrete-steel building, where the roof beams of concrete were carried beyond the walls

of the building and made to support a gallery, which serves as a lightning-arrester house; thus, the satisfactory introduction of the wires into the building and a proper fireproof room entirely separated from the station for the location of the lightning arresters, is provided. The iron brackets on which the wires are first supported, may be set either in the floor of the gallery or in the wall of the station. In either case all water drips from the wires before the latter turn vertically to pass through the floor of the gallery. At the same time any small amount of rain, snow or dust which may blow up into the gallery will not continue on through the second hole into the station. Moreover, the two apertures, one leading into the gallery and the other from there into the station, being at right angles to each other, prevent any large amount of cold air entering the station. One building provided with this form of admittance was not particularly uncomfortable though the outside temperature was as low as 27° Fahrenheit below zero. The maintenance of proper insulation is always insured; proper mechanical fastening of the line wires secured, and the reliability and simplicity is all that could be desired.

MR. SKINNER:—It should be noted that Mr. Floy's plan does not contemplate in any way taking up the end strains of the line wires. This must be done away from this point.

The other communication I have is from Mr. O. H. Ensign, Chief Electrical and Mechanical Engineer of the Edison Company of Los Angeles, California.

MR. O. H. ENSIGN:—We use, for 30,000 volts, plain 12-inch sewer-pipe wide open. Our temperature never goes to zero. It is cold only for short periods. I do not believe that unless considerable protection is given in the way of extension of the building, any sort of glass plate or marble supporting special insulators would be satisfactory, exposed to the weather.

MR. SKINNER:—Here is another discussion by A. L. Mudge.

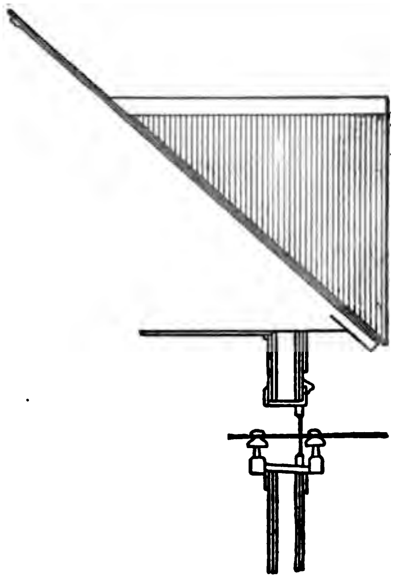
MR. MUDGE:—Would suggest that the terra cotta should be closed at outer end to prevent birds and insects getting into, or building nests in, the pipe. I find that a good ice and snow break on a sloping roof is V-shaped, and is much stronger than a single horizontal strip and also tends to let the roof free itself of snow. These strips can either be made of wood or of two lengths of angle iron bolted to the roof.

PRESIDENT SCOTT:—Another from Mr. F. C. Pierce.

MR. PIERCE:—Referring to the article: Page 80. Art. (5), (C), I do not believe in allowing the wall of the building to take the strain of the line, the last poles of the line should be braced or guyed; the number of poles guyed being determined by the number and weight of the line wires. In all cases I have seen, the wall, even if very heavy, will eventually come loose or bulge.

Where the strain is taken on the line; a X-arm just outside and one just inside the wall, fastened rigidly to the wall, will hold the wires in the centre of the slab of insulating material and exert no strain thereon.

I enclose rough sketch of our method of entering wires in the power house.



We found it necessary in cases where we enter under the eaves as in the sketch on p. 83, Fig. 2, to put a false dormer above the entrance, as otherwise the ice and snow slides down, catches on the wires and accumulates between the wires and eaves until the wires are either broken or pulled out of place.

The substation wires enter the gable ends. The slab of insulating material is 12" x 12" plate glass with 2" hole through center. Since putting the dormer on power house we have had no trouble whatever from our entrance wires.

[Discussion Contributed by J. Harisberger.]

My experience has been with the construction as shown in sketches 1 and 2, pages 81 and 83. The Snoqualmie Power Company adopted at the very beginning the arrangement shown in Fig. 2, and with all of its high-tension troubles, it has yet to experience its first trouble with this style of construction for entering buildings. In some of the buildings the wires enter with the construction shown in Fig. 1 and in every instance when the high-tension lines became grounded for one reason or another, there was a discharge across the glass plate to the terra cotta pipe and which is evidence, in my opinion, that with a voltage as high as 30,000 it is not the best, unless a terra cotta pipe of an unpractical diameter is used.

[COMMUNICATED BY M. H. GERRY, JR.]

Mr. Skinner has stated the essential requirements for entering high-tension wires. There are a number of excellent methods in common use, all of which give good results when properly ap-

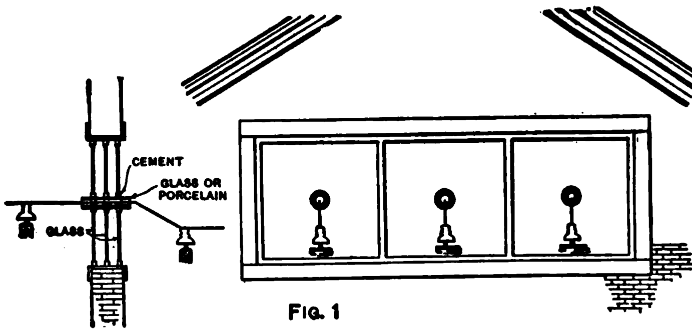


FIG. 1

plied. Fig. No. 1 is an excellent construction in use in several plants operating at 40,000 volts. This arrangement consists of a double, or triple, window sash set in an ordinary frame, the glass having openings in the centre in which are placed insulating bushings, or tubes. A water shed to keep the rain from the glass is sometimes added.

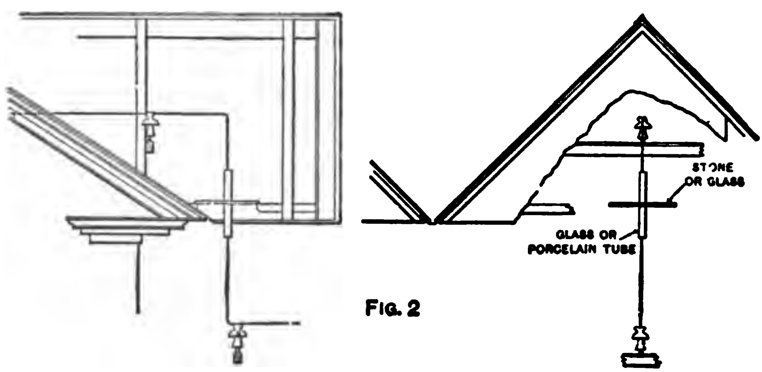


FIG. 2

Fig. No. 2 is a method frequently advocated, and in use for moderate pressures to a certain extent. It can be made to give good results, but involves special building construction.

Fig. No. 3 is a common method of entering high-tension wires through tile pipes. This method is an excellent one, and will give good results even up to pressures of 30,000 volts. Entrances of this design should always be made, if possible, through gable end of the building and not under the eaves, as shown by

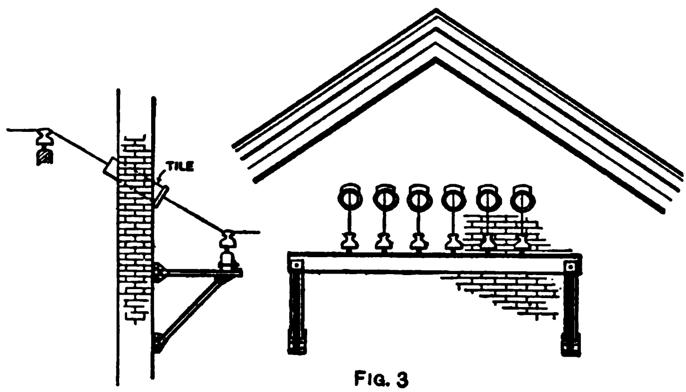


FIG. 3

Mr. Skinner. If impossible to enter at the end of the building, then a rain-shed should be provided over the wires, this being especially essential in cold climates, where ice forms readily.

Fig. No. 4 is a simple method of entering high-tension wires as applied to an iron building. The glass tubes shown are four feet in length two inches in diameter, and from five-eighths to three-fourths of an inch in thickness. This method is now in regular use at 50,000 volts.

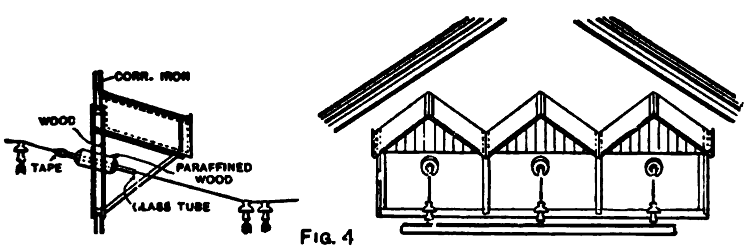
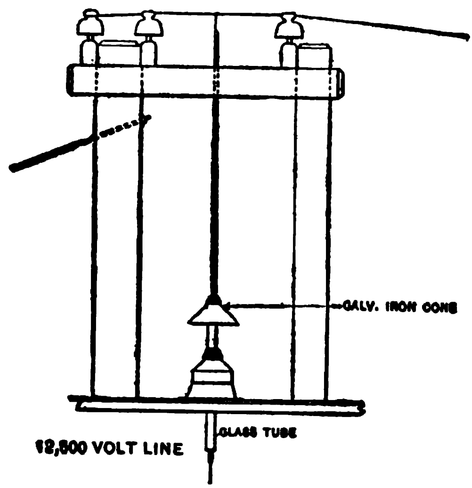


FIG. 4

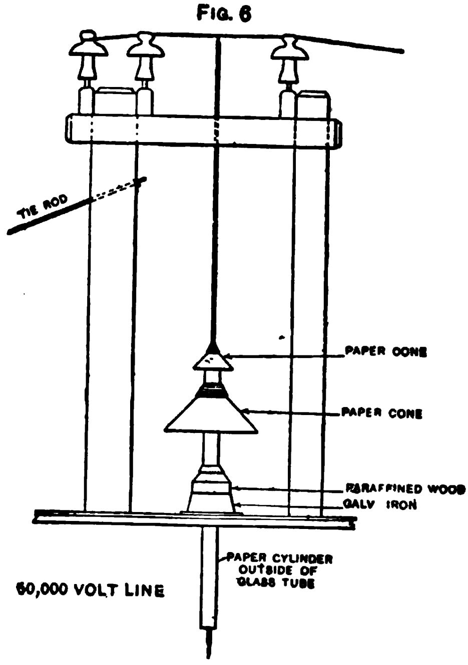
Figs. No. 5 and No. 6 are methods of entering wires vertically through the roof. Fig. 7 is a detail of the roof insulator, used in connection with the arrangement as shown in Fig. No. 6. The drawings show the construction clearly and require no explana-

FIG. 5



END ELEVATION

FIG. 6



END ELEVATION

tion. These vertical entrances are in use at the Canyon Ferry Plant of the Missouri River Power Company, and give good satisfaction. The above methods are selected as representing current practices. There can be no one method of entering high-

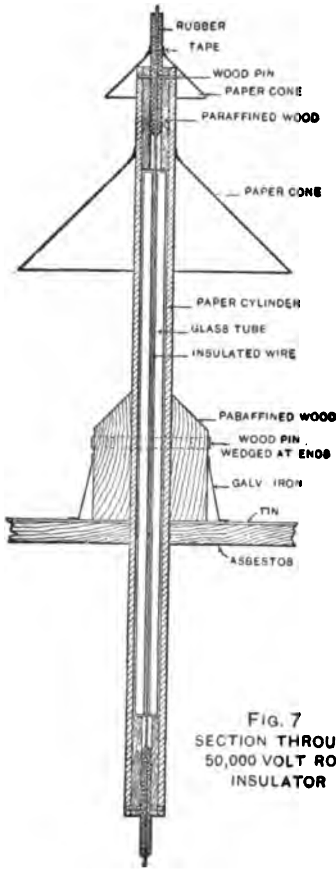


FIG. 7
SECTION THROUGH
50,000 VOLT ROOF
INSULATOR

tension wires. It is always a question of engineering detail, which should receive special treatment in each particular case.

PRESIDENT SCOTT:—Mr. Skinner's paper, on the "Methods of Bringing High-Tension Conductors into Buildings," is open for discussion.

MR. MERSHON:—I have used a number of different methods of bringing wires into buildings, some of which have already

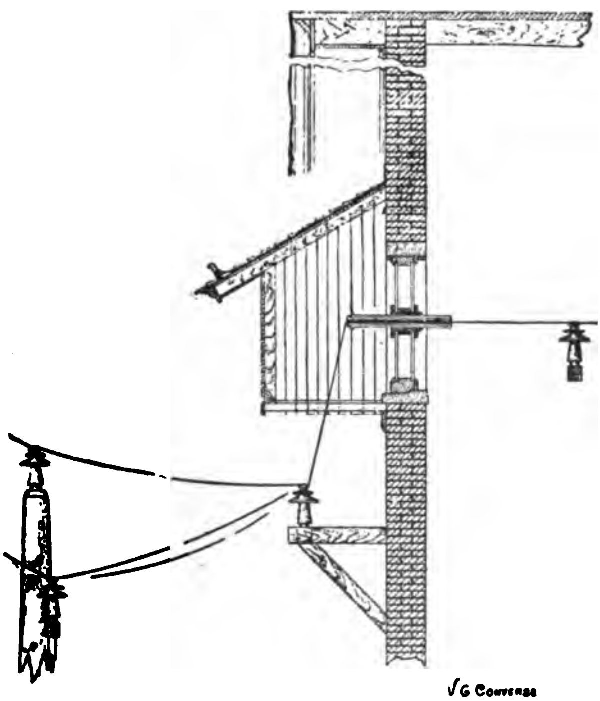
been described. The method of a tile and a flat glass plate, has been used, I think, quite a long while; also that of a glass tube in a wooden bushing going through the wall, for voltages of 25,000 or 30,000. The latter is a good method of bringing wires into buildings except for the difficulty of getting glass tubes. Some times I have had no difficulty in getting satisfactory glass tubes; at other times tubes obtained from the same manufacturer will all go to pieces if, being warm, they are subjected to a blast or draft of cold air, such as would result from opening the door of the station. So I have come to feel a little bit afraid of the use of glass tubes.

Now, as to the size of the glass plate and the distance which the voltage will go over it. Some time ago I had occasion to install a tile and a glass plate arrangement because there was not time to get anything else, and the largest tile obtainable was 24 inches. That size was put in on a 50,000 volt line, which has been in operation in all kinds of weather for four or five months without any trouble. At times the frost gets so thick on the glass that you cannot see through it and, if the line has been shut down for a little while and a great deal of frost has collected, there is a discharge over the glass until the frost is melted; but after it is melted near the wire the discharge stops almost altogether. Although we have had no trouble at all in this case, I think a greater distance than 12 inches over the surface of the glass plate from the wire to the tile in a brick wall is advisable for this voltage. I think this question of entering buildings is a good deal like the question of insulators, in that it depends somewhat on the climate. There are places where the climate is such that the method I have just described for a 50,000 volt circuit would undoubtedly give trouble.

Mr. R. F. Hayward:—There is no doubt that the question of climate cuts a very big figure in the selection of the methods for entering buildings with high-tension wires. I think this method of using a tile is open to objection, and a good deal of trouble comes from it. I do not think that any outlet which has for its protection a covering for building outside the power house where the wire comes in, then up and then through, is very nice, for the reason that birds do get in. The most successful outlet that I know of is one that was put in at the Murphy mill and has been running on 40,000 volts for, I think, four years. There is a brick wall in the gable end. The outlets are, I think, four feet apart. The holes in the brick are, I think, 18 inches. They may not be more than 14 inches. In those are set two plates of glass, each plate of glass flush with the outside, then another flush with the inside, of the brick; a hole about 2½ inches in diameter drilled through this and another glass tube placed in it. There was great difficulty, as Mr. Mershon has mentioned, in getting good glass, but they have got it, and that glass has never broken. There has never been a short-circuit or a breakdown, and that gable end faces the southwest storms, where all the

sleet and rain comes from. We are using that kind of outlet for all our work in Utah, only instead of using the glass tube we are going to use porcelain tubes, because I think we can get them stronger, and we shall simply increase the size of the plate glass to about two and even three feet square. I think that people do not appreciate how effective in practice a simple piece of plate glass is. On 16,000 volts I have a piece of 12-inch plate glass with a $\frac{3}{4}$ hole drilled in it and wires passing right through, and have never had the slightest trouble, although we frequently have severe storms in winter. I think that the most important thing in outlets is lots of space and not cumbering the outside of your building with any extra structure. Leave it clear, so that nothing can get up against it, and where everybody can see it.

MR. V. G. CONVERSE:—I am hardly prepared for an impromptu discussion, but I have a few ideas on this subject, one of which I think is of the utmost importance with very high voltages. It is that the insulation into a building should of itself be protected. It should be protected so that anything coming in a



horizontal line, such as rain, snow or dirt that is blown will not decrease the resistance of the insulation. Two figures show the extension of the roof brought down to such a point that to my mind it leaves off just where it begins to be of value.

The tile shown in Fig. 1, seems to me to possess a very bad feature in being left open on the exposed side. This construction may suffice, and I know of several cases where it is in use, but it certainly is open to the objection of being free to receive anything that may lodge in it. I think that Fig. 2 is a much better construction, but it could be improved upon by using several tubes, rested one within the other. Mr. Mershon has stated the objection to glass tubes, and I would recommend the substitution of porcelain. I do not think that porcelain is always a good article to use, but it is in this case. Suitable glass tubes are not made in this country and are very difficult to get anywhere, while porcelain tubes are a standard article of manufacture and they can be gotten in lengths up to three feet, I believe, and in a variety of diameters, which will nest very satisfactorily. I would make the further suggestion with reference to Fig. 2, that instead of one glass plate, there be two glass plates, spaced some five or six inches apart. This will give additional support, and afford an inside space which should tend to prevent the accumulation of frost. As to the point of the extension of the gable, as first mentioned, I think that there is the insulation of the whole structure. To my mind, the most uncertain point of the insulation in Mr. Skinner's second figure is the surface distance from the outer end of the tube over the glass plate. This cannot be very many inches and should be protected. I would advise that the gable be extended down to a point considerably below the wall insulation. The line wires should be carried from the anchor pole to a point several feet below this gable, and up to the tube insulators and into the building. The lines may be held in this position by a bracket supported on the wall, below the gable. If the lines are heavy they may be further supported by line insulators within the gable, so that there will be no strain on the tubes or glass plates. I furnish a sketch embodying my ideas.

MR. P. H. THOMAS:—To my mind Mr. Converse's suggestion of a rain-shed is an excellent one. By extending the roof a considerable distance from the wall and running it low down, building a baffle-plate from the ground up, leaving just sufficient opening to carry the wires in, and carrying the wires down and up as he suggests, you get the conditions of an indoor inlet at the main wall, where the plate glass and tubes are used. With the possible exception of the temperature outside, the conditions or interior construction will be admitted to be very much superior to those out of doors. Now, by changing the usual out-door inlet to an indoor inlet nine-tenths of the trouble would be avoided, and this can be easily done by the rain-shed spoken of. Sometimes it might be more convenient to obtain the protection by bringing the the rain-shed inside the building; that is, have a large opening in the wall and building a small room or large box up near the top, for bringing in the wires and then putting the true inlet on the farther wall, where it would be thoroughly protected from the weather.

There is one other point; ordinarily, I think a great deal will be gained in the long run by mounting the true high insulating inlet in an insulating panel, made as nearly fireproof as possible—something of the nature of marble would of course be the best—but with a large number of substations this would be too expensive. For a great many climates, it would be wise to use a wooden panel in which to mount the glass or porcelain inlet. This panel in such a case should if possible be made of a number of different pieces of wood with the grain running in different directions, and should of course be as well treated and prepared as possible. There is a certain danger of fire, but this is a minimum, I think, with good construction, and with the rain-shed of which we have spoken.

MR. P. M. LINCOLN:—There is just one point in the scheme mentioned by Mr. Converse that I would like to bring up, and that is the matter of taking up end strain. If you adopt that scheme, you have got to take up your end strain on the line outside of the building. That means taking it up on the standard insulators with the usual pins. Unless there is a special construction it is difficult to take up the strain on a heavy line in that manner. The end strain should be taken up by a strain insulator inside, as represented in Mr. Skinner's sketch No. 1. The great advantage of that to my mind is that the end strain of the line is taken by the insulators mounted inside the building, and you can put your insulator in any position, without having petticoats in such a position as to fill up with water and become useless.

[COMMUNICATED AFTER ADJOURNMENT BY DR. LOUIS BELL.]

For all high voltages, I prefer the arrangement shown in Fig. 2 in Mr. Skinner's paper. It is thoroughly effective and has the great merit of demanding ample space between wires. A mania for compactness has been responsible for more trouble in high voltage systems than any other one cause with which I am acquainted.

Wire towers for high potential lines should be avoided, first, last and always, together with tunnels, conduits and every other device for getting high-tension wires compactly stowed away out of sight. My own personal rule is to use wide spacing and to carry all wires in obtrusively plain sight until they get out of the building and go upon the line proper.

The high voltage wires themselves and all their connections should be so placed that their whole arrangement is evident from a cursory glance, and the higher the voltage the more need for caution in this respect.

A paper presented at the 20th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., July 1, 1903.

THE GROUNDED WIRE AS A PROTECTION AGAINST LIGHTNING.

BY RALPH D. MERSHON.

Some of the transmission lines of this country have installed upon them as a protection against lightning one or more wires strung parallel to the power wires and grounded at intervals. There is a difference of opinion amongst those operating such lines in different parts of the country as to the efficacy of this device. The importance of the subject makes it desirable to have an expression of opinion upon it from those members of the INSTITUTE who have had experience in operating such lines or who have given the matter close consideration. This can perhaps be best arrived at by a discussion on the subject.

THEORY.

There are three ways in which lightning can affect a transmission line; by a direct stroke, by electromagnetic induction and by electrostatic induction. Protection against the first of these would be almost impossible, certainly impracticable. Fortunately, lines are not often struck by lightning. The second, electromagnetic induction, is, in the opinion of the writer, a theoretical possibility—nothing more. It is against the effects of the third, electrostatic induction, that lines are to be protected, whether by lightning arresters or by grounded wires.

The theory of the electrostatic induction action may be explained with practical accuracy as follows: The whole transmission system, line, transformers, etc., may be regarded as an electrostatic conductor, insulated from the earth. Suppose a

cloud heavily charged with, say, a positive charge, to move up to the region over the transmission line. There will be a positive charge "set free" on the transmission system and it will have a tendency to pass to earth. It will pass to earth by gradual leakage over and through the insulation of the system if the approach of the cloud is slow enough to give time for such leakage; if not it may puncture the insulation and thus pass to earth. The intensity of the charge will depend upon the potential at the line wires due to the charge of the cloud. Suppose there be near the transmission wires other wires parallel to them and grounded at frequent intervals. They will also be subject to the inductive action and the charge set free upon them will pass to earth as fast as liberated, the "bound" charge of the opposite sign of that of the cloud remaining and depending for its magnitude on the potential due to the cloud and the electrostatic capacity of the grounded wires. Under these conditions the intensity of the charge on the transmission wires will no longer depend only upon the potential at them due to the cloud, but upon the combined action of the charge of the cloud and the bound charge of the grounded wires. In other words, the potential of the line wires will be equal to the difference of the potentials due respectively to the cloud and the grounded wires and will in general be less than that due to the cloud. This action constitutes what may be designated as the "shielding action" of the grounded wires.

Return now to the condition where with no grounded wires the system has been gradually charged and the charge has gradually leaked away, leaving a bound charge of negative sign on the system. Suppose now the cloud be discharged by a lightning flash to earth. The potential due to it at the transmission wires is now zero and there is consequently left upon the transmission system the negative charge which was previously "bound" but is now "free" and which has a tendency to pass to earth and will probably do so suddenly, since the charge has been rendered free suddenly. Its passage to the earth may mean a puncture of the insulation of the system. If, however, we assume that the grounded wires are again present and the charge bound on them by the cloud and set free upon them by the lightning flash can readily pass to earth, there will be less tendency towards the puncture of the insulation of the system because of the fact that, as previously explained, the impressed potential of the line wires before the flash is less with the grounded

wires than without them. If the charge on the grounded wires cannot pass readily to earth the charge on them will tend to set free a negative charge on the line wires, which will be added to that set free on the line wires by the lightning flash. The worst condition would be that under which the charge on the grounded wires could not pass to the ground at all, in which case the sum of the two charges on the line wires will be just equal to that which would have existed if there were no ground wires. The passage of the charge from the grounded wire to ground will always be more or less obstructed by the inductance of the discharge path, the effectiveness of this inductive obstruction depending upon the suddenness with which the cloud discharges. This inductive action of the ground wires due to the charge left upon them we will designate as the " direct action " of the wires.

The " shielding action " of the ground wires may be calculated by making assumptions which will approximate to a degree those which obtain in practice, but the calculation of the " direct action " is less satisfactory since it involves a number of assumptions, all more or less speculative in their nature. This is due amongst other things to the fact that we cannot know how long the lightning flash will last or whether it will be oscillatory or not. Furthermore, we do not know what the dielectric strength of the insulation of the system will be for periods of time so short as those involved under the conditions mentioned. We do know, however, that under the worst conditions that can obtain the insulation stress due to the " direct action " of the grounded wires can be no greater than though they were not present and will in general be less. We also know that whatever be the maximum value of this insulation stress it will diminish rapidly either in an oscillatory or non-oscillatory manner, the rapidity of the diminution depending upon the freedom of the discharge path from obstruction. It is to be noted that the time-element of dielectric strength is not involved in the calculation of the " shielding action " to the degree that it is in the "direct action"; since in the former case the charge comes on to the system more or less gradually and we may assume without great error that ordinary values of dielectric strength hold.

In order to get an idea as to the magnitude of the " shielding action " let us calculate its effect under the most simple conditions. Suppose we have two No. 00 wires stretched side by side on a pole line 20,000 feet in length, the wires being one foot

apart. Call these wires A and B. Suppose first that both wires are insulated from ground and that the space occupied by them is raised by the inductive action of a cloud to a potential v above the earth. The expression for the potential of a long cylinder or wire of length l and diameter d, having upon it a charge whose density is δ is

$$v_1 = 2\,\pi\, d\, \delta \log_e \frac{2l}{d}$$

The potential outside such a wire at a distance s from its axis is

$$v_2 = 2\,\pi\, d\, \delta \log_e \frac{l}{s}$$

Each of the wires A and B has upon it, therefore, a free charge of such a density that

$$V = 2\,\pi\, d\, \delta \log_e \frac{2l}{d} \therefore \delta = \frac{V}{2\,\pi\, d \log_e 2\,l/d}$$

Now let one of the wires A be connected to earth. The free charge on A goes to earth leaving a "bound" charge whose density is equal and opposite to that of the free charge or

$$-\delta = \frac{-V}{2\,\pi\, d \log_e 2\,l/d}$$

The potential of any point distance s from the wire A and due to the bound charge of density $-\delta$ is, therefore,

$$V_1 = -2\,\pi\, d\, \delta \log_e \frac{l}{s} = -\frac{V \log_e l/s}{\log_e 2\,l/d}\, s$$

The resultant potential therefore at any point distant s from the axis of the wire A due to the combined actions of the charge on the cloud and the bound charge on A is

$$V + V_1 = V\left[1 - \frac{\log l/s}{\log 2\,l/d}\right] = V\left[1 - \frac{\log l - \log s}{\log 2\,l - \log d}\right]$$

This expression will give the resultant potential at the wire B when A is grounded, if we substitute in it the value $l = 20{,}000$, $d = .3648$ inches $= .0304$ feet $=$ diameter of No. 00 wire and $s = 1$ foot. Substituting these values we have

$$V + V_1 = .297.V$$

It appears therefore from this rough calculation that if each wire of a transmission line 20,000 feet in length, the conductors of which consist of No. 00 wire, have stretched parallel to it and

at a distance of 12 inches, a grounded wire equal in size to the line wire, the potential of the line wire due to a charged cloud could not rise to exceed 30 per cent. of the value to which it would rise if the grounded wire were not present. As a matter of fact, if each of the line wires had its corresponding ground wire the potential to which they could rise would be even less than this because each line wire would be influenced not only by its own grounded wire but by all of the other grounded wires also. However, it is not usually the practice to employ a grounded wire so large as that assumed, and 12 inches is a smaller distance from grounded wire to line wire than would usually have place. The usual variation from these quantities will about compensate for the effect due to a greater number of grounded wires as usually arranged, so that the example taken serves its purpose as furnishing a criterion as to the magnitude of the effect of the grounded wires. It does not and is not intended to furnish a criterion as to construction or practical details.

Material and Dimensions of Ground Wires.

Ground wires are usually of galvanized iron. This material is probably as good from an electrical standpoint as any other, since with the rapid flow which must take place at discharge the material of the wire itself will probably make little difference in the obstruction offered to the flow. The size of the wire will have an important bearing since in general the larger the wire the less obstruction it will offer and also the greater its "shielding action." Greater effectiveness will be obtained of course for a given amount of material from a number of grounded wires of smaller size than from a smaller number of larger size. Barbed wire is often used for grounded wires but in the opinion of the writer it has no advantage over smooth wire. It seems to have been adopted with the idea that the points would in some way discharge the atmosphere, but if the accumulation of a charge on the line wires is in accordance with the explanation already given the points cannot be effective in any way.

Method of Installation.

Usually three grounded wires are installed, one on top of the pole and one on each end of a cross-arm. They are generally tied to glass insulators presumably for mechanical reasons, as all three wires are of course grounded. The wires should be grounded as often as possible, so that the obstruction to the flow between grounded wire and earth shall be kept as low as possible,

thus keeping down the direct action of the grounded wire to as low a figure as possible.

Results in Practice.

The writer has known of a number of plants where grounded wires were installed. In one of these, as the result of a number of years of operation, those in charge of the plant feel sure that the grounded wires furnish a reliable and effective protection against lightning. In some of the other plants those operating think that the grounded wires furnish more or less protection but are doubtful as to the amount. In still other plants those in charge feel sure that the grounded wires are of no value whatsoever and constitute a nuisance and menace because of their liability to break and fall across the power wires. In some of the cases of doubtful success or failure the trouble may have been due to poor grounds or to the wires not having been grounded frequently enough, as in some of these cases the wires were not grounded at every pole. In all of the doubtful cases lightning arresters which were installed in addition to the grounded wires received more or less discharges during thunder storms.

DISCUSSION OF "THE GROUNDED WIRE AS A PROTECTION AGAINST LIGHTNING."

PRESIDENT SCOTT:—This is certainly a very important and very interesting topic, one on which it is very difficult to secure complete and definite information. The conditions surrounding the problem are indefinite and hard to determine, as in fact are all experiments in connection with lightning work. We should be very pleased to hear from those who have had experience with this subject. I think Dr. Perrine has had something to say on this in the past.

DR. F. A. C. PERRINE:—From my own experience, I would say, that there seems to be no question but that a grounded wire on a pole line properly grounded does benefit in lightning protection. In relation to the question as to whether barbs are used or not, I agree with Mr. Mershon that they can have comparatively little effect in discharging the atmosphere, for the reason that the atmosphere that we wish to discharge is a moving atmosphere and not a stationary one. If the atmosphere were a stationary one the barbs on the wire would undoubtedly aid in the discharge. On the other hand, after a cloud has discharged in the neighborhood of the line, and the line and its accompanying guard wire has reached a stationary condition, just before the bomb charge is about to disappear from the line through the ground circuit, I believe that the points on the grounded line will tend to aid the release of the bomb charge from the power line; and while there is not much in favor of the barbs, it would be my opinion that if it is possible to obtain a wire with a point on that is not thereby mechanically weakened, it would be advantageous to obtain such points. But such a wire is not on the market. I agree that it is not wise to fool with barbed wire, because you can get much greater permanence with simple twisted strand wire or single wire.

There is one point that has not been brought out, and that is the question of possible loss of energy due to inductance to the grounded wire. On one line that I am familiar with they claimed that there was a very serious loss of energy due to electromagnetic induction to the grounded wire, the grounded wire making short circuits parallel to the line. I made some tests on this and could not find anything that seemed to be really appreciable. I would also like to call attention in reference to the communication that Mr. Mershon read, to the fact that the power line at Lachine, where they have found no trouble, although only protected by lightning arresters, is a line of long iron poles, where the earth-tension is undoubtedly brought nearer the line than would be the case with wooden poles. We have no practical experience except with one or two lines such as the Lachine line.

MR. MAILLOUX:—In one line in Arizona 25 miles long, which connects at a station at one end, a receiving station at the other end, and a second power station about eight miles from the

receiving end, no provision was made for lightning protection except by spark-gap lightning arresters at the stations. In other words, the line, a 3-conductor line, about 25 miles long, with transmission voltage of 22,000 volts, has only three points at which it is protected by lightning arresters. I was curious to know what had been the experience, and wrote to the operating engineer, Mr. D. W. Beldon, one of our members. He replied that the line had never been without current since it was started, last fall; that notwithstanding the fact that there had been many lightning storms, including one which occurred while the load was at its peak, there has never been any trouble at all from lightning. There is a discharge over the lightning arresters, but it has never been such as to interfere in the slightest manner with the operation of the line.

MR. A. J. WURTS:--I am pleased to note that Mr. Mershon does not recommend altogether abandoning the spark-gap lightning arrester.

I do not agree with him where he states that " this discharge will pass to earth by gradual leakage over the insulation of the system if the approach of the cloud is slow enough to give time for such leakage." I do not believe that the velocity of the cloud has any immediate influence on the static charges in overhead wires as to whether they leak to earth or become disruptive. I consider the cloud or upper storm strata and the earth to form the two terminals of a huge static machine and I think you will agree with me that a lightning discharge does not start from a single point but that the main discharge as we see it is made up of a large number of smaller tributary discharges which in turn are made up from still smaller sources, very much as our water sheds are ultimately concentrated into one large stream or river. I believe the same to be true in the earth terminal, that there also are tributary discharges from all sources of electrostatic capacity and from all directions toward the main stroke. I believe that all electric wires, grounded or otherwise, car rails, gas pipes, water pipes, all form a part of the earth terminal of this huge static machine and that a grounded wire in the neighborhood of an insulated electric line will not materially protect that line but that all will discharge alike and that the discharge will tend to be disruptive with every discharge of the the static machine—with every stroke of lightning. If there is any virtue in the theory of the leakage of the static charge, surely this ought to manifest itself in our trolley wires, all of which are thoroughly well grounded as far as leakage is concerned, although for disruptive discharges it is admitted that the ground connection is of no avail, owing to the large inductive resistance intervening between the overhead wire and the ground connection.

I am sure you all know that wire fences, gas pipes, and even gilt mouldings around a room will give off discharges during a thunder storm, and these discharges, as I take it, are due to the

release of the electric stress by the lightning discharge breaking through the dielectric. The charge then which had previously existed in all bodies having electrostatic capacity, seeks to establish a path to the main lightning discharge; so that every piece of metal, every conductor, whether " grounded " or otherwise adds to the capacity of the earth terminal. I have even noticed discharges between parts of large steel buildings.

Admitting now that discharges do occur from all kinds of conductors, it would appear that the overhead grounded wire could hardly be considered a reliable source of protection because if it really did protect, I do not believe that we would obtain sparks from the inside metallic parts of buildings, protected (?) as they are by well grounded water pipes, forming the best possible overhead grounded wire.

MR. THOMAS:—I do not know of results where all the conditions have been carefully investigated and where it is definitely known that there has been trouble without a grounded wire, that it has been stopped by the addition of a grounded wire, and (to make the proof of the efficiency of a grounded wire complete) we should have also the other case, where the removal of the grounded wire shows the beginning of trouble again. Such a case would be very unlikely and in its absence we must wait for a very large number of ordinary tests.

In regard to Mr. Mershon's assumption as to the nature of the effect of lightning upon the line, he concludes that it is practically all electrostatic induction, but I believe he is hardly justified in neglecting the electromagnetic entirely.

In discharges which come to the ground in the immediate neighborhood of the line, we certainly cannot neglect the electromagnetic effects. The difficulty of protecting oil tanks and powder magazines even with a considerable amount of grounded conductor in the neighborhood is also well known.

Dr. Perrine has spoken of the losses on grounded wires close to transmission lines. I am surprised to find that it does not amount to anything. I should think it probably would be considerable, and if the grounded wire is made of considerable conducting power, *i.e.*. low ohmic resistance, I imagine there will be found quite a little loss; and more than that, if these grounded wires are placed close to the transmission line, as must be done to get effectiveness, it must considerably increase the electrostatic capacity of the system. This might be a serious item in a large plant. The problem is very complex and I think we should go very slow in staking too much on grounded wires.

Another point on which I think Mr. Hayward can give us some information—it is generally supposed that the striking of the lightning to the ground is the most harmful feature. I am inclined to believe that the discharge within the cloud in a more or less horizontal direction will produce a much more destructive effect upon a transmission line which happens to lie somewhere near parallel to the line of this discharge than a vertical discharge will.

Dr. Perrine:—I would like to speak a word, Mr. President, in explanation. I see Mr. Thomas has distorted my statement that I could not find a loss, to the statement that I found no loss. There is a good deal of difference between the two. The matter is difficult to measure. I tried to measure it, and couldn't find it. I didn't say it wasn't there.

Then there is another point that I want to call attention to now that I think this discussion is getting a little mixed on, and that is, that there are two things to protect against. One is the gradual charge and discharge of the line due to conditions of the atmosphere, and it may be that a line is at a high potential at one part of the country and at a low potential at another, or that the line is gradually acquiring a charge from the wind blowing over the line when there is no lightning in the neighborhood, and in perfectly clear weather you can have that. It is against this form of trouble that I believe that the guard wire is of most advantage. I do not believe that the guard wire is of any very great advantage when you have lightning discharges of severe character. There you do get, as both Mr. Wurts and Mr. Thomas have stated, an electromagnetic effect as well as electrostatic but the gradual charge and discharge of a line that would come in perfectly clear weather is a very nasty thing, and, as I said, one line that I saw myself, 46 miles long, which Mr. Mason was handling with me, was the only line, as Mr. Mason remarked, that he ever succeeded in taking hold of when there was no dynamo connected with it, in dry weather, without getting a shock. He attributed that almost entirely to the protection of the neighboring grounded wire.

Dr. A. E. Kennelly:—This is a very interesting and important subject and one that must always be of great practical consequence, because it is one of the standing difficulties in our transmission line work. We can protect against the regular difficulties, but lightning is one of the difficulties that cannot be reckoned with. Experience in this matter extends to a much earlier date than is generally supposed, because in a certain sense we have experience on this question for at least 50 years, in the protection of telegraph and telephone wires. It is true that the effects of lightning in telegraphy are of much less consequence than in a power transmission system, because the amount of property that may be damaged in telegraphy by a lightning stroke is comparatively small. Nevertheless, the experience which can be accumulated on the long wires in telegraphy bears upon the experience which we seek to accumulate in the protection of transmission lines. It has been a popular impression derived from many years' experience in telegraphy that the presence of neighboring overhead wires does protect against indirect lightning effects. Of course, we know that when we speak of the direct flash nothing can afford protection, but in regard to these surges due to lightning discharges in the vicinity, there is a strong popular belief among telegraphists, that neigh-

boring wires do protect. If we know anything at all about lightning—and we do not know very much—it is that when we put a conductor wire under ground, or in an electrical conducting shell, that the buried wire is freed from electrostatic disturbances, and also, to a certain extent, freed from electromagnetic disturbances. We all believe that a buried wire, disconnected from all apparatus, is in no danger of a lightning stroke, induced or otherwise. When grounded wires are carried over and above, or in the neighborhood of, a working wire, the earth is virtually raised over that wire, or in the vicinity of that wire, and we partially produce that effect which a completely buried wire more thoroughly attains. I think, therefore, it stands to reason, that if only there are grounded wires enough over and above and around a working wire, immunity from indirect lightning surges is brought to that wire. But whether it is worth while incurring the expense and trouble of stringing the grounded wires around the working wire is another and a different question. Some years ago I had occasion to collect some information of this character from the representatives of local stations, and I found the evidence was somewhat in favor of protection by means of guard wires suspended in the neighborhood of the working wires.

The question of electrostatic capacity and its increases due to grounded wires on the working wires, is one of the minor considerations to be taken into account, but after there are three wires up in a three-phase overhead system, the extra capacity that can be given by adding other wires is comparatively trivial. It is the first extra wire that counts, and when you have several wires up together side-by-side it would not seem that the electrostatic difficulty is going to be a serious one. The amount of energy which may be wasted, in transformer fashion, from the main line to the loops of the grounded lines as secondary circuits, is also a matter to be considered, and I do not think that it has been worked out. It would seem, therefore, that there is an advantage, theoretically at least, in having grounded wires around working wires, but the disadvantage of having to string extra wires around a transmission system is very serious.

Mr. Lincoln:—Mention has been made of the electromagnetic as well as the electrostatic effect. I wish to call attention to the fact that these grounded wires are to a certain extent a protection against electromagnetic as well as electrostatic effect of a lightning discharge in the neighborhood of the transmission line. The grounded wires constitute a short-circuited secondary and the induced effects from the lightning discharge in the neighborhood will be largely absorbed by that short-circuited secondary. In a solid metallic conductor you can get no electromagnetic effect; so the ground wires may approach that condition.

One other point which has been brought out before, is in regard to the discharge by the grounded wires of the atmosphere which blows across the line. Mr. Mershon does not treat of that in his contribution, but I think it is an important point. In this

climate we do not get that effect so much as in the West, because the atmosphere here contains much more moisture.

MR. F. S. WOODWARD:—I would like to speak of just one practical point in regard to barbed wires on a line that I am familiar with. For about two years after erection they remained in good condition, then began a series of breaks due to rusting. Nearly every break of a barb wire was followed by a short circuit in line wires. As a result of this experience the barb wires were replaced with No. 4 B. & S. iron wires. The extra cost of larger size iron wires was more than offset by lesser cost of erecting.

This line had ground wires every six poles. The ground wires were brought about half-way up the pole and then divided, passing up at extreme end of cross-arms. This to some extent protected linemen when at work, as otherwise they were in contact with the ground return.

MR. RUSHMORE:—There is one point which I have not heard mentioned. If a transmission line runs through a mountainous country where a considerable difference in latitude exists between different parts of the line, there will be an electrical effect, due apparently to the difference in altitude which causes a much greater difference of potential between wires and ground in the low than in the high altitudes. In some instances it is known that a considerable difference of potential exists between the base and summit of mountains. A grounded wire strung along the line should be of assistance in the prevention of trouble from this cause.

MR. R. S. KELSCH:—The Lachine Rapids Hydraulic and Land Co., Ltd., of Montreal, Can., operating a general overhead distributing system for light and power work, at 2200 volts three-phase, has experienced considerable trouble and suffered damage to transformers principally, from lightning.

When this company began operating, there were five telegraph, telephone and electric light companies operating in the city of Montreal—which compelled the Lachine Rapids Company to construct 95 per cent. of their lines below the lines of other companies. A careful record kept of the eighteen circuits indicated that the greatest amount of trouble, such as transformer burn-outs, etc., caused by lightning, occurred on the circuits that were built under the lines of other companies. When this record was started, it was supposed that the circuits running into the open districts where there were no wires above them, would show the greatest number of transformer burn-outs, etc., but the result was just the reverse.

MR. JOHN F. KELLY:—I believe that the main protective effect of the grounded wire is not against lightning discharges, but principally against the ordinary atmospheric electricity. We all know that with a difference of a few yards in elevation we may find a difference of several thousand volts, and a wire suspended at any distance above the earth will in time gain the same potential as the air or bring the air to its potential. The charge so

accumulated on a wire will discharge to earth when the conditions are favorable, the most favorable place being usually determined by the weaknesses in transformers and dynamos. As to the accumulation of that charge, the rate at which it accumulates, I remember in the old telegraph days, before the dynamo service was much developed, in western New Jersey, in the hill country there ran a telegraph line through a tunnel, and was protected by lightning arresters. Well, they couldn't put in lightning arresters fast enough 20 years ago to keep that line in service. There was trouble in calm weather, when there was no sign of disturbance in the neighborhood at all. Then, when the alternating current service was first introduced, I remember watching a line in the hills of Connecticut. The sparking on the lightning arresters was constant on account of the atmospheric charge even in fine weather, although the line was only a few miles long. The circuit-breaker, in connection with the lightning arrester, was high chattering all the time. Now, I think it is against electricity of that nature that the grounded wire is of service, if it is of any service at all.

The most important point in Mr. Mershon's paper, to my mind, is that, if his theory is correct, the grounded wire may be placed below and yet be equally as protective as if placed above. No one heretofore has attributed any protective effect to the grounded wires when below the working conductors. The great danger in even laying it heretofore has been, that being above, in breaking, it would fall on the transmission wires.

But as to how much protective effect it really has, I think there is considerable doubt. Mr. Mershon has referred to one line on which it appears to protect perfectly. I think I recognize the line, and on that line there are a lot of water crossings, the ærial line at each crossing being replaced by a sub-aqueous cable, and at each of these crossings both sides are protected by lightning arresters. So that is one thing, The other thing is difference in elevation between the two ends of the line. The effect of hilly country, to which Mr. Rushmore alluded, is not very pronounced there. And the third thing is that they never have run without the grounded wire. On the other hand, I know of a plant in the south where they have put in grounded wires and then grounded them as often as they could. It is, however, a pretty bad country to obtain good grounds in as the clay soil takes hold deep down in the dry season. A number of the grounds have been made in water courses and some have been kept artificially wet, but I think they have not been able to find any improvement whatever. My own feeling is that while there is some protective effect from the grounded wire, that it doesn't pay for the complications.

It has been said that the electrostatic effect on the working conductors is of no importance, but I think when you get lines 150 or 200 miles long with a very high voltage and ordinary frequencies, it becomes highly important, especially if one uses

a single grounded wire not set in neutral position. I have never seen a grounded wire so placed. If it is set out of the neutral position it will affect not only the amount of electrostatic line charge but it will affect its distribution, so that the flow will be different on the three legs of the line. The disturbing effects of a balanced electrostatic charge are bad enough.

In the seventh edition of Culley's Handbook of Practical Telegraphy, p. 126, the use of individual ground wires on the poles, not connected by an overhead conductor, is described. Several able telegraph engineers have told me that this type of line construction has given them the same protection in nature and amount that the overhead grounded conductor is said to afford. Obviously, Mr. Mershon's condenser theory cannot apply here, and in consequence, these observations tend to throw doubt on the completeness of the theory.

Mr. Hayward:—I wish to suggest to the Committee on High-Tension Transmission, that they send out word to every operating engineer, to everybody who has any stations of high-tension lines under his charge, and ask that every one of their engineers operating under them be made an observer; to have everybody working under them make careful observations, not only when the storm is on but when the storm is coming, as to what happens —time it as nearly as possible, record it in a log book. In the case of a breakdown from lightning, let him go right to the spot as if it were a fire, and let him collect the evidence right then and there, and at the end of a year or two we shall all know far much more about this lightning question than we know to-day.

I think that the location, other than the elevation,—the nature of the ground—has a great deal to do with lightning discharges. I think where you have a broad valley and your lines are lying in the valley near the base of a mountain, that you will get discharges which on the average are quite different.

Our system embraces 20,000 volts and some 400 or 500 miles of high-tension circuit spreading over a country that is about 150 miles long. Starting in the old days when the insulation was low, with 2000 volts, when all the wires were in the trees, we never knew any lightning trouble in any shape. As we improved our installation our lightning troubles came on us more and more, and now, carrying 20,000 volts, with lines thoroughly insulated, we know what lightning means. I do think that overhead grounded wires, such as telephone and telegraph wires, are a protection, for this reason, that I have never lost a transformer in our business section which is the most thickly covered with other wires. But they are not complete protection by any means, even at 2000 volts, for although our lines at Salt Lake City are almost all on the same poles as the telephone wires, yet the telephone wires do not entirely protect them. At the same time, we cannot help feeling that if you absolutely surround your wires with a grounded network, that they must be protected, except against perhaps some great stroke of light-

ning, so to speak. However, that is absolutely impracticable from our point of view. We have had many and many an instance where there has been a sudden discharge of lightning, and almost instantaneously, or immediately following, there has been a jump from the lead outside the transformer to the case of the transformer, rather than going through the transformer coil. We have had a lightning discharge smash up the insulators on the line, cut into the station, jump from the lead coming from a transformer from 16,000 volts, cut off the transformer and the puncture papers in the lightning arresters never show any discharge. Now, all those occurrences which we have all show the same sort of effect. Our troubles come at the moment when the lightning discharges. Troubles due to the raising of the potential of the line when there is a dust storm, or wind storm or a thunder cloud, are taken care of on the lightning arrester. I have never heard or known of any trouble from that. Every single occurrence that has ever given us any trouble has been at the moment of the lightning discharge.

MR. JOHN F. KELLY:—Mr. Hayward, I think, is probably right as to his having no trouble on very high-tension lines from atmospheric electricity, but the conditions are very different on lines of moderate-tension or low-tension, like telegraph wires. On a high-tension line the voltage with which one is sealing on the line is itself of a magnitude comparable with the atmospheric difference of potential discharge, and consequently when the dielectric strength is made sufficient to resist the puncturing of the insulating material, puncture by the charge accumulated by the wires is also presumably guarded against. But on low-tension circuits, where the normal voltage is much below the difference of potential that may arise from atmospheric charge there is no such guard against atmospheric effects.

PRESIDENT SCOTT:—Mr. Hayward has the difficulties which come to engineers through coöperation. He is trying to coöperate some three or four different plants in different places and in different directions from Salt Lake City, and which have been laid out with different voltages and under different conditions, as separate independent plants entirely,—the old Pioneer plant at Ogden, the Utah Power Company, the big Cottonwood, and now, I believe, he is linked in with the Telluride Power Transmission Company. Is there any further discussion?

MR. W. L. WATERS:—I did not quite follow Mr. Mershon's theoretical calculation, but I would like to suggest an alternative calculation, which has the advantage, from my point of view, that gives results which agree more with my own practical experience.

Let us assume that a cloud has just discharged, and that we are left with an induced charge on the transmission wire which raises this wire to a high potential above the earth, and we wish to find out to what extent the presence of a grounded wire will lower this potential. The system which we have to consider

consists of the transmission wire B, carrying a charge Q_1, the grounded wire A, carrying an induced charge Q_2, and the earth G, also carrying an induced charge. For the purpose of calculation, the earth can be considered as an infinite conducting plane, and by Lord Kelvin's theory of electric images the distribution of electricity induced on the surface of the earth can be replaced by charges $-Q_1$ at C, which is the image of B, and $-Q_2$ at D, which is the image of A. Then we have for the potential of wire A

$$(1) \qquad V_2 = p_{ab}\,Q_1 + p_{aa}\,Q_2 - p_{ac}\,Q_1 - p_{ad}\,Q_2$$

where p_{ba}, p_{ac}, etc., are Maxwell's coefficients of potential. And assuming that the diameter of the wries is infinitely small compared to the distance between them, these are given by the expression,

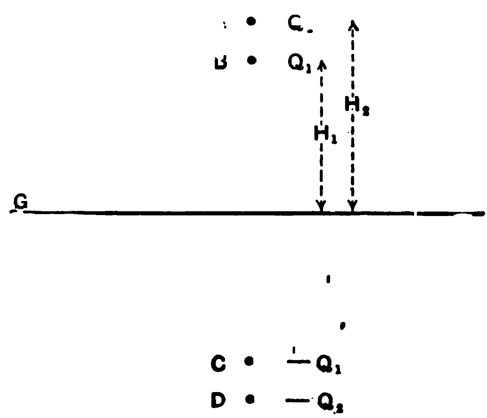
$$p = -2 \log r$$

where r is the distance from the center of one wire to the center of the other.

But as the wire A is grounded its potential V_2 is zero. Thus putting $V_2 = 0$ in equation (1) and solving for Q_2 we get

$$Q_2 = Q_1 \frac{\log \dfrac{H_2 - H_1}{H_2 + H_1}}{\log \dfrac{4\,H_2}{d}}$$

where d is the diameter of the wires.



Similarly, we have for V_1 the potential of the transimssion wire B.

$$V_1 = p_{bb}\,Q_1 + p_{ab}\,Q_2 - p_{bc}\,Q_1 - p_{bd}\,Q_2$$

substituting for Q_2 in terms of Q_1, and evaluating we get

$$V_1 = 2\,Q_1 \left\{ \log \frac{4\,H_1}{d} - \frac{\left(\log \dfrac{H_2 - H_1}{H_2 + H_1}\right)^2}{\log \dfrac{4\,H_2}{d}} \right\}$$

Assuming the ground wire not present this becomes:

$$\overline{V_1} = 2\,Q_1 \log \frac{4\,H_1}{d}$$

so we get as the value for the shielding effect:

$$\frac{\overline{V_1} - V_1}{\overline{V_1}} = \frac{\left(\log \dfrac{H_2 - H_1}{H_2 + H_1}\right)^2}{\log \dfrac{4\,H_2}{d} \cdot \log \dfrac{4\,H_1}{d}}$$

Taking the numerical value used by Mr. Mershon, *i.e.*, No. 00 wires 12 inches apart, and taking the height above the ground as 30 feet, we get the shielding to be 25 per cent. Taking what perhaps is a more practical case, No. 4 wires 24 inches apart, we get the shielding to be 14 per cent., which is rather different from Mr. Mershon's result.

But I think that a theoretical discussion of this subject is not very much to the point, because we really know very little about the conditions in the phenomena which we are discussing. It is also extremely difficult to get any reliable practical information as regards the effect of the ground wire because unless we do as Mr. Thomas has suggested, *i.e.*, try a number of transmission lines both with and without a ground wire, we cannot really get any definite information. The fact that one transmission line is satisfactory without a ground wire and a second one is also satisfactory with a ground wire gives us no really definite information.

My own experience has been confined to European conditions, *i.e.*, short mountain lines worked at 5,000 to 10,000 volts. The conditions under which they work are violent lightning storms, and heavy sleet and snow storms during certain seasons of the year. The sleet and snow storms very often bring down the ground wire, producing a short circuit, and the screening effect of the ground wire does not seem to be very appreciable in a lightning storm. So that the general opinion of operating engineers is that the ground wire is far more trouble than it is worth.

MR. CURTIS:—In this discussion I notice that several gentlemen have referred to the failure of telephone lines located above power leads to protect the latter from lightning or electrostatic induction. When we take into consideration the fact that modern telephone lines are composed of metallic circuits almost exclusively and are not grounded, their failure in this respect

hardly seems strange, and further if they actually *do* afford the slightest shielding action it must be accounted for by some other theory than that pertaining to grounded wires. I believe the same statement is practically true of telegraph circuits, which are rounded normally only at their extremities, which would render them ineffective owing to conductor resistance, except for exceedingly short distances from their terminals. I have known long metallic telephone circuits, with clear weather prevailing their entire length and breadth, to give off electrostatic discharges sufficiently severe to destroy the coils connected to them, the current of course seeking the shortest path to ground.

PROFESSOR D. C. JACKSON:—The problem which exists with respect to protecting a line from sparking to ground or surrounding parts, no matter what the cause, is to keep the line as nearly as possible at the same electrostatic potential as the ground. Now undoubtedly the grounded guard wire does something in that direction, and Mr. Mershon is right in making his computation and saying that there is some effect from the guard wire; but on the other hand, he has not taken data of such a form and of such numerical values as to give results that may be considered to be always applicable, or adaptable to commercial conditions in a long and important transmission line. For instance, the guard wire in Mr. Mershon's example is taken too close to the line wire, and since the protective effect is dependent upon the logarithm, as the guard wire gets further away from the line the falling off of the protection is enormously rapid. I therefore think Mr. Mershon is misleading us by taking his one foot distance; he is exaggerating the effect.

There is another element that Mr. Mershon has omitted, which has a great deal of influence. You must bear in mind that if one has an induced discharge upon a transmission line and guard wire due to a cloud overhead, and that cloud discharges into a cloud at some distance, or discharges to earth, there is an almost *instantaneous* change of the potential of the earth under the line at certain points and also of the atmosphere surrounding the guard wire. The resistance of the guard wire, its inductance and capacity enter to modify the instantaneous change of the charge in the guard wire itself and consequently the guard wire during this period (because of resistance, self-inductance and capacity), is unable to exert its full influence to protect the line wire; and Mr. Mershon has omitted to introduce the effects of the self inductance and capacity and resistance of the guard wire and its ground connections into his formula. I think that he has omitted them because they cannot yet be put in, for the reason that we do not have a reasonable knowledge of their values under the conditions and therefore have no way of representing them in the formulas. So I say Mr. Mershon is right in presenting the matter as he has, but he is without question exaggerating the effect of the guard wires, and very largely exaggerating it, when he says that it may be expected to afford a protection of some-

thing like 70 per cent. I think if this was taken at 7 per cent. or 7/10 of 1 per cent., it perhaps would come nearer the truth.

MR. MERSHON:—I think that in general I agree with Professor Jackson—but I would like to take up one or two points in connection with what he has said.

As regards the theory of the matter, I agree pretty thoroughly with Professor Jackson. I will not commit myself too far, however, in that regard. As regards what Mr. Waters has said, I made an assumption in treating this matter, on purpose to keep the problem simple. I assumed that the space potential at each of the two wires was the same. I think if the wires are in the same horizontal plane it is a pretty fair assumption, and this is the relative position which most frequently has place in practice.

As regards the size and distance between wires, I am not so very far wrong. If I remember rightly, the distance I have taken as between the wires is exactly that which existed on a line on which it was claimed the ground would give very good protection. The size, also, was approximately that which I have taken; for barbed wire was used whose effective size, because of the twisted strands, is considerably greater than a single wire of an equivalent section. For most cases in practice I think the figures I have given furnish a fair sort of criterion. I have purposely avoided the questions of oscillatory effect, of self-induction and all those complicated questions which require elaborate assumptions of questionable accuracy.

It seems to me that the question of electromagnetic action is one of amperes and frequency, and not of volts, as Mr. Thomas has stated, and it is hardly conceivable to me that the currents at the distances that flashes often occur would be great enough to affect the line seriously from electromagnetic action.

Now, as regards the position of the cloud, that changes the problem to some extent, but I do not think it changes it altogether. The shielding action, even if the cloud is affecting only part of the line, would have place to a considerable extent.

As regards the discharge of the atmosphere itself—suppose the particles of air or moisture around the wire are charged, isn't it likely that the effect of the inductive action due to the great mass of particles beyond the wire will be considerably greater than that of simple leakage from those particles to the wire, if there is such a leakage effect? The flash between clouds, it seems to me, does not alter the problem so very materially. You have the effect there of a redistribution of charge, and you still have to a considerable extent the shielding action of the grounded wire.

As regards the difference in altitude, I have gotten the altitude effects in a great many cases and it never seemed to me necessary to explain them by leakage from the atmosphere. Simply because you cannot see a cloud, is no proof that it does not exist. The cloud need not necessarily be a mass of moisture; it may be air under some condition differing from that of the surrounding air; so that in considering a charged cloud, we should

consider any mass, whether it be moisture or whether it be air of a different density from the air around it, and which might accumulate a charge on the surface of separation between it and the surrounding air.

As regards protection from electromagnetic effects, if there are any, the resistance of the ordinary grounded wire would be too high, and the self-induction too high, to furnish much protection, especially as you cannot conveniently ground the wire any oftener than at each pole.

As regards the gathering of data, the grounded wire is taken up in the lists which the Transmission Committee are sending out, many of which are coming back filled in. We should be only too glad to get the minute attention to the subject of lightning protection, as well as other points taken up by these lists, that Mr. Hayward advocates, and we shall certainly expect to get a fine lot of data from Mr. Hayward's plants.

Mr. W. J. Hammer:—Last fall I had the pleasure of spending some days investigating the Valtellina 20,000 volt, 3-phase Railroad in Italy constructed by Messrs. Ganz & Co., of Budapest, Hungary.

I remember that one of the methods of protection used was a drain pipe filled with water, which acted as a water resistance, and which was connected to the wires and to the ground, the intention being that while there would be ordinarily no leakage, when lightning passed over the circuit these would act as a protective device. The main reliance, however, was placed on a form of lightning arrester which by its simplicity commended itself strongly to me. I understand that since these have been put in place no lightning has ever entered the power-house, and it is claimed that there is no necessity for lightning arresters inside of the power-house.

The device, which was placed just outside the power-house, consisted of three funnels, one attached to each of the 3-phase circuits, being supported by porcelain insulators. Underneath each funnel is a little spray of water which is thrown up so that it is a short distance from the funnel, but not making contact therewith. Should any abnormal voltage appear on the line due to lightning it is carried off by the jets of water.

Mr. W. A. Blanck:—I will state that in most of the Italian and German high-tension lines lightning arresters are used only in power stations and substations and seldom on the line itself. The use of iron such as barbed wire along the line for protection of the same from lightning has been abandoned.

The lightning arresters mentioned by Mr. Hammer are used on the Valtellina Railroad in northern Italy and consist of a small reservoir which furnishes constantly dripping water to the various wires of the high tension system. The small drops of water upon reaching the wires are charged and upon leaving them carry off this charge and in this way very satisfactory results are obtained.

MR. MERSHON:—I would like to hear from Dr. Perrine and some of the other members who have spoken of the losses due to a grounded wire as to how that loss could occur and as to the nature of it. Do they mean atmospheric loss. It seems to me that with grounded wires, especially if the neutral of your system is grounded and you have between the grounded wires and the line wires anything like the distance there is between line wires themselves, you will not get much loss. For you are then concerned with a voltage a great deal lower than that between the line wires and you presumably keep the atmospheric loss between them pretty well down.

MR. MAILLOUX:—I want to caution Mr. Mershon, in his statement about the loss due to electromagnetic effect caused in the parasitic circuits, constituted by the grounded sections. He says that the resistance of these segments would be a protection against loss. I think that there is a certain resistance at which that loss will be the maximum. If we have an infinitely great resistance, of course we would have an e.m.f. there, but no current. With an infinitely small resistance we would have a reactance loop in which you would have a full counter e.m.f. effect and very little loss excepting the small $I^2 R$ loss necessary to keep the large current flowing; but there is between those extremes a critical resistance which corresponds to the maximum loss. Evidently, we only have a differential e.m.f. due to the difference between the electromagnetic effects of the three wires. If the conducting wire could be placed in the center of the triangle perhaps the resultant effect would be negligible anyway.

PRESIDENT SCOTT:—The paper we will take up now is: "On the Testing of Electrical Apparatus for Dielectric Strength." by P. H. Thomas.

A paper presented at the 20th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, July 1st, 1903.

THE TESTING OF ELECTRICAL APPARATUS FOR DIELECTRIC STRENGTH.

BY P. H. THOMAS.

It is evidently very desirable before depending upon apparatus for commercial service, to have assurance that it is in proper operating condition and also, where the apparatus is built to specification, that the specification has been met. The only practical method of determining the condition of the apparatus as regards its insulation is by means of over-potential tests. *Potential tests have been used for a number of years and have been found to be in general quite satisfactory.* However, in common with all types of tests which depend upon the application of abnormal strains, over potential tests have certain drawbacks and involve certain risks. A brief discussion of such objections, especially in regard to insulation tests upon very high tension apparatus, will be found in the following pages.

(1) A disruptive test fails partially of its object in testing the fitness of the apparatus for actual service, because the conditions of the test do not approximate closely the conditions of the service, either normal or emergency conditions.

(2) Serious injury may be done to the insulation of the apparatus by the test, even under apparently favorable conditions, so that failure may result afterwards in actual service.

(3) In making tests on finished apparatus, it is impossible to test each portion of the insulation separately and the result of many types and forms of insulation being coupled together, is that only that which is weakest with regard to the particular conditions existing at time of test will be tested.

(4) In general, electrical apparatus is never in a condition so poorly adapted to stand dielectric strains as when first installed.

(5) Insulation tests require special testing apparatus and expert and *experienced* direction which are very often not available, and without which great risk is run in attempting such tests.

(6) As an exception to the above (paragraph 5) it is evident that some simple types of apparatus, such as insulators, high tension bus bar insulation, high tension series transformers, etc., may be readily tested without great danger.

(7) Fuller consideration of paragraph (1). Potential strains upon dielectrics cause effects of two kinds:

(*a*) A constant tendency to puncture the dielectric, which is caused directly by the presence of the potential and depends on the physical dimensions and nature of the dielectric, and which probably remains constant as long as conditions are unchanged; *e.g.*, physical or chemical state. This strain is almost mechanical in its nature.

(*b*) A tendency to heat or produce chemical change in the dielectric, largely the former. This heating also is caused by the voltage and is very much more marked with alternating current than with direct current. Though comparatively small in actual amount, this generation of heat is a dangerous thing, as it occurs within the body of the insulating material which is usually a poor conductor of heat.

As insulation heats up, it becomes much less able to withstand the strain described in paragraph (*a*) above, and, further, the rate of generation of heat within the insulation itself becomes much greater. As a net result, if insulation under strain once reaches a sufficiently high temperature, it is practically certain to get hotter and hotter and ultimately to break down. In other words for continuous running it is necessary that the heat generated by the potential in the dielectric be dissipated as fast as generated. In tests of actual apparatus, the critical rise of temperature may be reached in as short a time as one-tenth of a second in some cases, or in other cases perhaps only after a long time, perhaps an hour. As long a time as an hour would be required only in large bodies of insulating material; *e.g.*, in large capacity or high-tension apparatus.

Different kinds of insulating material are affected by the strains described under (*a*) and (*b*) in very different degrees. Gaseous dielectrics suffer substantially no heating, while solids and liquids usually have their breaking-down strength determined by this heat factor.

In actual service, injuries to electrical apparatus usually result from overheating, dirt, moisture, chemical exposure, mechanical injury or wear due to vibration and occasionally a strain from lightning or over-potential stress. The latter strains, however, are rarely extremely severe, except as they may cause local concentration of potential in the windings of apparatus, as will be discussed later.

Thus the volage time test, which is usually applied to finished electric apparatus, by no means reproduces all the conditions of actual service. On the other hand, it is of course true that apparatus which will stand a high disruptive test will usually stand better in service, so that such a test is of value.

If a high disruptive test is relied upon by a purchaser to determine the acceptance of apparatus and to terminate responsibility on the part of the manufacturer, the latter will be tempted to design his insulation in such a manner as best to stand the disruptive test at the sacrifice of some features more valuable for preventing deterioration in actual service. This difficulty becomes a very serious one where unusually severe disruptive tests are specified in a contract.

(8) Fuller consideration of paragraph (2).. With low-tension apparatus, little or no harm is to be expected from reasonable over-potential tests carefully made, provided insulation is in good condition. An exception should perhaps be made of dangers of local concentration of strain in high tension generators or motors of small size, as will be explained later. The following discussion applies to high tension apparatus chiefly.

The amount of heat generated within the body of a dielectric increases at least as fast as the square of the voltage. Further, this loss, with constant voltage, may be increased several times by an increase of 100° C. in temperature. This means that a strain of double potential continued for any length of time strains the solid insulating material far beyond any condition it will meet in service. Further, the ability to stand the strain will be determined rather by the facility for getting rid of the heat, which is usually of little consequence in commercial work than by other features of the insulation more desirable for actual service; further, the hottest part of the insulation will be inside, so that the center portion of the material may be badly charred, while the outer portion, the only part visible to the eye, has been kept cool and appears uninjured. This means that very serious injury to high tension apparatus may be entirely beyond the

possibility of detection until further developed by actual service.

Potential strains above a certain critical point cause a tendency for brush discharge over any insulating surface. If continued, this will deteriorate the insulation so that a discharge may continue afterwards at a lower voltage. This effect will occur even under oil, and, like the internal heat, will not be visible to the eye until in a very advanced stage.

When a coil is charged to a high potential and one end is suddenly discharged, there is a strain equal as a maximum to the full value of the discharge voltage, tending to cause the charge upon the turns of the coil to jump to the terminal through the insulation across the turns rather than pass around these turns. Since this total "discharge voltage" may be the abnormal voltage at which the apparatus is being tested and since this abnormal strain may be concentrated on a portion of one coil, where many coils are used to withstand the normal voltage of the circuit, it is evident that certain turns of the coil (which lie next to the terminal which is being discharged) will receive excessive strain. The condition which is essential to produce this concentration is that the discharge of the terminal of the coil shall be extremely sudden. This can usually occur only when the terminal is discharged by a spark close to the terminal itself, electrically speaking, *e.g.*: any accidental or other discharge between the wires used in applying the test, or in the apparatus itself, will tend to puncture insulation between turns at certain points within the winding. Such injury will oftentimes not be discovered, as the apparatus being tested is not in a condition to show a short circuit when it is not connected to a generator. This danger is very serious with extremely high voltages. Apparatus may be protected against this strain by the use of choke coils, or high resistances, or static interrupters in the leads of the apparatus to be protected, provided no discharge occurs nearer the apparatus than the protective device. In this connection it should be noted that if the spark gap is used as an auxiliary to measure the potential of the test, satisfactory means must be used to prevent a dischagre on the spark gap from causing injury to the apparatus being tested.

The emphasis placed upon this particular phenomenon is not for theoretical reasons only, but because, in a number of actual cases, serious injury has resulted to apparatus therefrom. Furthermore, such conditions have been reproduceed for purposes of investigation.

(9) Fuller consideration of paragraph (3).

In testing finished apparatus, it is manifestly impracticable to subdivide the windings into more than a very limited number of parts, *e.g.*: in case of the transformer, into more than possibly four parts. When such a portion is subjected to disruptive tests, a breakdown may evidently occur in a number of ways, *e.g.*: between portions insulated only by air distances; over a surface of insulating material, which may be marble on terminal block, fibrous material or possibly the surface of oil in an oil insulated piece of apparatus. Furthermore, breakdown may occur through solid material, which in some places will be well ventilated and in other places will not be well ventilated. Sometimes portions of this material which in the disruptive test receives full strain, may when running in commercial service be so located as practically to receive a very much less strain. Such a point, for instance, would be the neutral point of a three phase, star wound generator. It is thus clear that if the severity of a test (as it must necessarily be) is determined by the strength of the insulation of the weakest spot of these various types and qualities of insulation, the other parts will receive an insufficient test. It may occur that a portion of the insulation less likely to give trouble in subsequent service will be this weakest portion, and will determine the whole test, leaving the condition of the other more vital portions of the insulation insufficiently tested.

(10) Fuller discussion of paragraph (5).

In tests made by persons inexperienced in such matters, there is grave danger of injury to apparatus which would not result when tests are properly made. Such difficulty may arise by the use of testing apparatus having too high an inductive factor or field reaction, so that current to the apparatus may either raise the voltage beyond the usual ratio or so deform the e.m.f. wave as to cause an excessive strain; or by making tests when insulation is not in good condition; or in preliminary trials, in allowing tests to be on too long, though perhaps at a slightly lower voltage than the voltage of final test; or by improperly determining the temperature of the apparatus; or in a number of other ways unnecessary to enumerate. Difficulty from this source is by no means of rare occurrence, and it is very difficult to avoid in large high tension apparatus.

(11) Precautions to be observed in testing.

The most important precautions to be observed in making disruptive tests are here summarized:

(*a*) Insulation of all apparatus to be tested should be definitely known to be thoroughly dry.

(*b*) All insulation surfaces and the apparatus in general should be clean and free from all kinds of foreign matter.

(*c*) The measurement of the insulation resistance will sometimes give an idea of the fitness of the insulation for test. This condition will usually be determined not by the absolute value of the insulation resistance, but by a curve of the variation of insulation resistance as the apparatus is being dried out. When it has been increasing for a period and finally becomes steady with steady temperature, the drying operation is probably fairly complete. *However, where air or oil spaces are included in the bulk of the insulating parts, these spaces may determine the insulation resistance so that no indication is given of the condition of the actual solid material.*

(*d*) Before applying a disruptive test, it should be definitely determined that the temperature of no part of the apparatus to be tested is above that at which the test is to be made remembering that tests of apparatus when hot, especially when very hot, are extremely severe.

(*e*) Electrical apparatus of large capacity, which necessarily contains considerable masses of iron and copper, lags behind the atmosphere in temperature changes, consequently when the atmosphere is damp and warmer than the apparatus, there is a tendency for the latter to " sweat or condense moisture upon its surface. This moisture will at least partially be absorbed by the insulation material and render the apparatus unfit for test; consequently, it is important in unpacking to open the packing case only when the air is cooler than the apparatus. *In case of oil-insulated apparatus, the insulation must be protected from moisture when once dried out until immersed ready for service.*

(*f*) The determination of the high-tension voltage actually reached during test is sometimes a difficult matter. The things to be avoided chiefly are the distortion of wave form or the change in ratio of transforming apparatus, or excessive drop due to the use of apparatus for applying the testing voltage, which is of insufficient size to supply the charging energy required by the apparatus to be tested. This subject deserves a full consideration, but has been so fully discussed elsewhere that further space will not be given here.

(*g*) In applying the potential of test to apparatus, the voltage should not be raised on the testing set to full value and then

applied to the apparatus, but after being connected to the apparatus should be increased rapidly by small steps, or continuously from a voltage not over one-half the final value. Also, the voltage should be raised so quickly that the time during which the last 10 per cent. or 20 per cent. of the voltage is being applied will be short, as compared with the prescribed duration of the full potential test.

(*h*) To prevent local concentration of potential which results from any spark or break down occurring near the apparatus to be tested when the latter contains coils; choke-coils, static interrupters, or resistance in series with the terminal of the apparatus to be tested may be used. The result essential to the avoidance of this local strain is the prevention of the strain caused by the above mentioned breakdown from being transmitted without being smoothed out to the windings under test.

Evidently a choke coil in the lead of the apparatus will allow a change of potential to pass through it only slowly and if this coil be made to have several times the choking effect of the smallest portion of the winding to be protected (next the terminal) which is considered to be able to stand the voltage of the test momentarily, the necessary protection will be obtained. It would seem that a resistance in the place of the choke-coil would serve the same purpose and in a measure it undoubtedly will. However, since the resistance does not absorb voltage until after considerable current strength has been attained, it is not as well adapted to protect from sudden changes of potential as the choke-coil. The static interrupter being merely a choke-coil whose power is increased by the use of the condenser, will act in the same manner as the choke-coil described above. Usually, however, except where static interrupters are provided for other purposes, the choke-coil will be found more convenient.

(12) No complete recommendations are here made for specifications for testing apparatus for dielectric strength, but a few suggestions will be offered on topics in which there is probably a considerable diversity of opinion.

(*a*) In high-tension apparatus, *e.g.*: 20,000 volts and above, only moderate, short time, over voltage tests should be specified in contracts.

(*b*) Such tests should be made once for all when the apparatus is known to be in good condition, preferably at the factory, by experts, to give assurance that the specification has been met. Such tests should not be made a second time.

(*c*) After installation, a considerably lesser test should be made upon the apparatus, which will detect any serious injury in transportation and installation. Any moderate deterioration due to absorption of moisture, etc., will right itself with service, provided no abnormal deterioration has occurred.

(*d*) It is preferable to make high potential tests by increasing the voltage upon the apparatus as it is designed to operate, one terminal at a time remaining grounded, rather than making a high breakdown test by voltage from an external source.

(*e*) On tests of very high-tension apparatus, such as generators and transformers, no breakdown gap should be used in connection with the determination of voltage. Any error in the voltage of test, provided precautions as to the proper size of testing apparatus are used, will be comparatively unimportant. In some cases the voltage of the testing device may be determined by means of a spark-gap before the apparatus to be tested is connected to the circuit.

It must be borne in mind that in the above discussion only the objections to over-potential tests and the dangers to apparatus involved, have been considered; and that it is not recommended that disruptive tests be abolished. Such tests may be and regularly are made successfully and are very desirable to insure good insulation in electric apparatus and to determine the fulfilment of specifications. The point it is desired to emphasize is that great care should be taken to avoid injury to apparatus and that excessively severe tests, especially long-time tests at high potential should be avoided.

MR. L. A. HAWKINS:—In regard to the use of choke coils for protective purposes in the leads between the testing set and the apparatus, although such coils are of value in preventing a destructive rush of current in case of the breaking down of the insulation of the apparatus, I do not think that their value is great as far as discharges outside of the apparatus are concerned. The testing set and the leads should be installed so that there can be no danger of an accidental discharge due to the breaking of the insulation of the testing set or leads. Consequently, unless a spark gap is used, there could be no discharges outside of the apparatus itself, in which case the choke coils would furnish no protection beyond that furnished by resistance in preventing destructive current flow in case of a breakdown of the apparatus. I believe that the best protection against puncturing of the insulation due to sudden discharge lies in sub-dividing the winding as much as possible and short circuiting the subdivisions by connecting both ends of each subdivision to the lead of the testing set.

I do not consider of much importance the objection raised in the paper that the weakest point is the only one tested. In practice it is the weakest point alone that is of importance. If that is strong enough to stand, the rest will take care of itself. Even in such cases as that cited, as in the coils adjacent to the neutral point in a three-phase grounded generator or transformer system, I believe that all the insulation should receive the full high-voltage test, for although under normal conditions the insulation of the parts near to the neutral point are subject to no high-voltage strain, nevertheless changing conditions of operation may necessitate a change in the connection of the apparatus, so that the part that was formerly at ground potential may receive the full line voltage.

As to the dangers introduced by the changes in voltage and wave-form in the testing set caused by the charging current, I believe that the best precaution is in employing a testing set of sufficient size relative to that of the apparatus to be tested, so that the charging current can have little effect on voltage or wave form.

I thoroughly agree with the statement that on tests of very high-tension apparatus no spark-gap should be used in connection with the determination of the voltage. I believe that the use of a spark-gap introduces danger to the apparatus and inaccuracy in the results of the test. Especially when oil insulation is employed, if the apparatus starts to break, the spark-gap will usually break simultaneously and will maintain the arc, while the oil closes the break in the apparatus and stops it almost instantaneously. Consequently, without very close inspection the original kick through the oil will pass unnoticed and the apparatus will appear to have withstood a potential as measured by the gap considerably higher than the actual impressed voltage under which it really broke down. On the other hand, when the spark-

gap breaks first it introduces danger to the apparatus due to the sudden rise in voltage as pointed out in the paper. If testing apparatus of sufficient capacity is used, the ratio of transformation can safely be relied upon, especially since this may be checked up before the actual test, under different conditions by means of the spark-gap.

MR. M. H. GERRY. JR.:—Tests of apparatus for dielectric strength, as well as for any other purpose, should be made under conditions approximating at least those of actual service. It is useless, and may be positively harmful, to make strength tests under conditions differing widely from those under which the apparatus will actually operate.

There can be no objection to testing under any conditions, samples of insulation which fairly represent the material as a whole, used in the construction. If anything, there should be more of such tests, and less testing under severe strains of the finished product. We do not think of testing a steel structure as a whole up to the elastic limit of the material, but rather we confine such tests to samples representing the whole, and after determining the characteristics, we ascertain from the dimensions of the various parts of the structure, whether it is safe as a whole, and conforms to the requirements.

It may be urged that we possess a lesser knowledge of the strength of insulating materials than of the physical qualities of materials of engineering construction. I doubt if this be a fact at the present day. Insulating materials possessing a very fair uniformity of strength may be obtained; samples having been tested to determine the dielectric strength, and the heating under continuously applied strain, etc., it is possible, allowing a proper factor of safety, to predetermine the amount of insulation required, with practically the same accuracy as the strength of the materials in most engineering structures. It then becomes a matter of inspection to see that the required amounts of insulation are applied in the course of construction.

Reasonable insulation tests of finished apparatus, under conditions approximating those of service, are of course of some value in detecting serious errors in construction, but they are by no means conclusive evidence that the apparatus meets all requirements.

Mr. Thomas' remarks in reference to the effect of temperature on insulating material are worthy of most careful consideration. In this connection it should be pointed out that insulation may deteriorate after leaving the factory, due either to continued heating at operating temperatures, to chemical change, to the absorption of moisture, or to other causes. Insulation designed to withstand very high dielectric strain, especially if intended to operate under oil, should be carefully handled and protected in shipment. As mentioned by Mr. Thomas, large masses of material such as transformer cores, have a temperature lag, which tends to condense moisture under some conditions. This

is a matter of importance especially in connection with the shipment of large high-tension transformers.

Mr. Peck:—I believe that apparatus should be tested under conditions which approximate as nearly as possible the actual operating conditions. Mr. Thomas advises the protection of apparatus under test by means of choke-coils or resistances inserted in the high-tension leads or in series with the spark gap where it is used for measuring voltage. These precautions are taken to prevent an abnormal concentration of voltage upon a few turns or layers of the winding when a sudden ground occurs or a spark-gap breaks down. If the apparatus while in service is to be protected by choke-coils or static interrupters, then it should be similarly protected during test; but if the apparatus is not to be so protected in service, it may be questioned whether it is legitimate to apply such protection during the test.

Mr. Thomas also advises a high test on apparatus before it is shipped, and a lower test after it is installed. The reason for this is that the insulation just after the apparatus is installed is in a weak condition due to the absorption of moisture during transit, and is not therefore in a condition to withstand severe tests.

The objection to this is that while the insulation is in bad condition, an excessive strain may occur and damage the apparatus. In fact, just after a plant has been installed when everything is new, and the men not accustomed to the methods of handling the apparatus, and the line has not been thoroughly tested, excessive strains are particularly liable to occur.

For these reasons it is my opinion that whether the apparatus is to be tested after installation or not, every precaution should be taken to put it into the best possible condition before it is placed in service.

Mr. Stott:—In regard to the testing of electrical apparatus, I think that the tendency of this paper is to discourage such things. Now, on what are we to depend for our factor of safety without an over-potential test. In all structural material for mechanical purposes we insist upon strength and we also insist upon a factor of safety ranging all the way from three to ten. Now, if we simply accept apparatus to run on normal voltage, we have absolutely no factor of safety protection. There may be one there, but we do not know it. There may be weak points developed and it is very much easier to take care of a breakdown of insulation on a test than it is in actual operation when you have a great many thousand kilowatts ready to burn it up. I think the tendency to discourage tests is distinctly against the best interests of the operating companies at all events, and therefore against the best interests of the manufacturer. Of course, there is a limit of safety beyond which a test should not be pressed, and that is a difficult point to decide, just what is that limit. I would say it should be 50 per cent. over-potential, 100 per cent. or 300 per cent.—the conditions will probably dictate just what that over-potential should be.

Reference nas been made to moisture on insulation. I presume that refers more particularly to armature insulation. I have been working on some experiments recently on that subject, as far as surface leakage goes, and the experiment was carried on something after this style: A creeping surface amounting to about 4½ inches of insulation was established and the test used in an atmosphere of steam—simple atmospheric pressure saturated steam—and that steam had apparently no influence whatever upon the surface leakage. The only thing that had any influence was the presence of dirt of any description. So long as the insulation was absolutely clean, we went up from 40,000 volts on a 4½ inch surface, and had no effect whatever. So that I think that that statement as to moisture should be qualified a little. The moment dirt of any description was introduced on the surface, such as particles of oil or carbon dust, or particles of dust and oil floating in the air, then the insulation broke down immediately in the presence of moisture.

MR. LINCOLN:—Mr. Stott makes the analogy between the testing of mechanical apparatus and the testing of electrical apparatus, which I think hardly holds. When you test apparatus for physical properties—iron, for instance—take a test piece out of each cast or from whatever it is desired to test, put it into the testing machine and break it. If that method were followed in testing electrical apparatus it would meet the approval of the manufacturers; to take a sample of the insulation, put it into the machine and test its insulating qualities. But when Mr. Stott buys a dynamo he doesn't strain the bed plate until he breaks it. That is somewhat analogous to the over-voltage strain on the insulation of a dynamo.

MR. STOTT:—I did not mean to apply a strain to break down insulation, but a testing strain that would guarantee that there was a factor of safety in that material.

MR. LINCOLN:—The tested part would determine that, it seems to me.

MR. STOTT:—It would not determine the workmanship, however.

MR. GANO S. DUNN:—In the latter case the test of insulation on the armature is as much to determine whether the proper thickness of insulation is present as to determine whether that insulation, being present, is of the proper strength. (Quality of insulation can be supervised but quantity at every point not so easily.) Therefore, I side with Mr. Stott in feeling that a certain degree of high potential test is necessary.

MR. THOMAS:—Gentlemen, if you will read the last paragraph of my paper you will find that I do not recommend abolishing high-tension tests. I distinctly recommend them, only that they be made reasonable.

MR. W. L. WATERS:—When the insulation is designed for any high-tension winding, the engineer who designs it knows, or should know, at what voltage that insulation will break down,

assuming that it is tried and that it is in perfect condition mechanically. What he wishes to test for afterwards is to find out whether the insulation was damaged during manufacture or during transit.

The usual experience in the testing room is that if the insulation of a machine is going to break down on the high voltage test, it will do so during the first few seconds during which the high potential is applied. The reason for this is that if the insulation is damaged at all, it is usually totally ruined in certain places, so that it breaks down almost as soon as the high potential is applied. So I think that a more satisfactory test than the one-minute double-voltage test usually given would be a considerably higher voltage for a much shorter period. Take, for instance, a 20,000 volt transformer; the insulation of this transformer, if in perfect condition, would probably stand 80,000 volts for several minutes. The testing room high potential test I would suggest in such a transformer would be 50,000 volts for ten seconds.

When the machine is installed and is just going to be put into operation, it is to be tested again to see if it has got damaged during transit. Then I think a much lower voltage test, say a high potential test at 50 per cent., above the operating voltage and an insulation test, would usually be conclusive as to whether or not the insulation was in satisfactory condition.

MR. C. E. SKINNER:—In regard to the duration of test for the determination of whether the contract is fulfiled or not, I think the recommendation of the Standardization Committee is quite fair both to the manufacturer and to the customer. Their recommendation is for a test of double the potential at which the apparatus is to be used, applied for one minute. Longer tests are liable to cause trouble, as stated by Mr. Thomas, and the manufacturer usually makes his own tests higher to determine whether or not he has succeeded in carrying out his designs to his own satisfaction.

Mr. Thomas has perhaps given the impression that a great deal of caution is necessary. Caution is necessary, particularly with very high potential tests, but I feel that such tests should be carried out on all apparatus.

In regard to the method of application of the voltage, I think this might properly come up under Mr. Thomas' paper and very little is said about this matter.

There are three principal methods which are in use: The static voltmeter in the high-tension circuit; the direct reading voltmeter used with a multiplier; and the ratio of transformation measuring the voltage on the low-tension side. The spark-gap is recommended by the INSTITUTE, but I agree with a former speaker that it is an unsatisfactory and dangerous method.

Theoretically the static voltmeter in the high-tension circuit is the best, but it is difficult to obtain an entirely satisfactory static voltmeter. The use of a multiplier in connection with a direct reading voltmeter is open to the objection of large consumption of

power on very high voltages and the difficulty of building and maintaining the necessary series resistance.

With large testing transformers the ratio of conversion is in most cases adequate for the purpose. There may be a slight rise of potential when the static capacity is considerable, but this is not of very great consequence. The amount is not sufficient usually to cause any particular damage, as the apparatus must have a strength considerably above the contract test in order to pass either without giving trouble.

In regard to applying the voltage, it is sufficient on low-tension apparatus, say, tests up to six, eight or ten thousand volts, to simply switch in the potential at which the test is made. There will be a rise of the e.m.f. across the testing terminals, but the factor of safety, if you may call it such, will be sufficient, or should be sufficient to stand this rise; and where hundreds and even thousands of tests are made every day, as they are in the large factories, it becomes quite a serious loss of time, in making the tests, if considerable time is taken to bring up the voltage. For the higher potentials, it is necessary to raise the potential gradually, and there are various schemes for doing this. One of the best is to have control of the generator. That is not always possible. Where we are obliged to make the test from a constant potential system, then it is necessary to introduce something in the nature of water resistance or of a step-by-step method, using very small steps. Where the capacity of the apparatus to be tested is quite small, such as insulators or small sets of cable, steps as large as 5 per cent. do not seem to be objectionable. Where the static capacity of the apparatus under test is large the steps must be smaller to prevent surges in the testing circuit.

MR. MERSHON:—I thoroughly agree with what Mr. Peck and Mr. Skinner have said. I have no love for what might be termed an "egg-shell" transformer. It seems to me that we want something that is going to stand a little rough knocking about. If we have to handle 40,000 and 50,000 volt transformers so gently, what is going to happen when we get up to the voltages that are being talked about 100,000, perhaps?

As regards the question of injury to the apparatus under test, at, for instance, double potential test for a minute. The problem is simply this, that we want to get apparatus which will meet and withstand the conditions of practical operation. Now we cannot state accurately and explicitly what those conditions are. Therefore, we cannot formulate explicitly any tests which will show whether or not the apparatus will meet them. The best we can do is to adopt tests which, in the light of experience, will probably come somewhere near telling us whether the apparatus is going to meet the practical conditions. It seems to me that a double potential for one minute is not any too high, and I can tell you that it is very comfortable to know, under some conditions that obtain on transmission lines, that your transformers have stood such a test.

In regard to when and where the test shall be made, I want to emphasize what Mr. Peck says. It seems to me that the test should be made after the installation of the apparatus. We want apparatus that is going to stand the conditions to which it is subjected after it is installed.

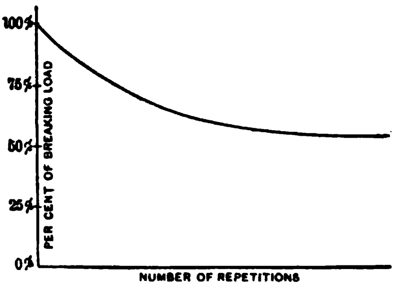
The stand taken by Mr. Peck regarding the improvement in the condition of the apparatus after installation, I agree with entirely. Presumably the manufacturer gets his apparatus in the best possible condition before it is tested. It is not fair that the severity of the test should be reduced in any way because the condition of the apparatus is going to improve with time, when in the meantime the apparatus may be damaged by lightning or other disturbances on the line, and the burden of that loss fall upon the purchaser.

MR. DUNN:—What we need to solve a good many of these questions is data on the relation between the elastic limit of insulating materials and their ultimate break-down point, just as we have that data for mechanical properties of various materials. To refer to the case mentioned by Mr. Lincoln, I think it would be good engineering for Mr. Stott to try to break the suspected base of the generator with a reasonable excess of strain over what it was expected to stand regularly.

Insulation testing is of two kinds. One, as I said before, to determine whether the insulation is present. This is necessary even if a manufacturer is honest, because in putting conductors into slots and wires around cores, considerable mechanical pressure and hammering has to be used, which is liable to break the insulation or subject it to such pressure that its properties are injured. The other kind of testing is to determine whether insulation which we believe present is good. In this test we apply a stress that is above the elastic limit. If we could determine that the elastic limit of the insulation was say one-third of the ultimate limit, it would be proper for us to use a high potential test within the former limit. The stresses we put on apparatus in factory tests now are above that limit, and we keep them on but a short time in order not to damage the insulation too much. Such tests, I think, are bad. If one of the results of this discussion were the collection of data on elastic limits, it would be of great benefit.

PROFESSOR LANGSDORF:—There is another kind of test, which so far as I know has never been applied to insulating material. It is analogous to those which are made upon metal, and recently upon cement, to determine the effect of fatigue. I have recently seen a curve which was made from the results of tests of this nature on cement that looks something like this (indicating); the number of repetitions necessary to produce failure are plotted as abscissæ, and percentages of the normal breaking load as ordinates. The curve is apparently logarithmic and approaches an asymptote passing approximately through the 50 per cent. division on the scale of ordinates; this

would mean that the factor of safety as ordinarily understood is only half the assumed value; so that if tests of this nature could



be made on insulators we might get a little more light upon the value of the factor of safety.

Mr. Henry Pikler:—When we are testing electrical apparatus we assume a sine wave e.m.f. This is true as long as the step-up transformer is directly connected to the terminals of the generator which furnishes the sine wave high voltage, but as soon as we use resistances in series with the transformer in order to control its terminal voltage the wave-shape of the e.m.f. changes. You know very well that the hysteresis, or more correctly, the change in the permeability during one cycle of magnetism distorts the wave-shape of the magnetizing current; but if we have it in the circuit besides the transformer, a series ohmic resistance, then this will cause the distorted current to change again to a sine wave. And when a sine wave current excites the transformer, its induced e.m.f. will be no longer a sine wave but a highly peaked wave, and we subject the tested apparatus to a voltage which is perhaps 20 per cent. higher than we are calculating on. I made some experiments in this regard, and I found that the more the energy consumed by the ohmic resistance comparatively to the energy consumed by hysteresis in the transformer, the less will be the distortion of the current wave, it will become more and more sinusoidal. But if the transformers get a sinusoidal magnetizing current, its induced e.m.f. wave will be distorted, assuming as a limit a perfect sine wave shaped exciting current. The induced e.m.f. wave of the transformer will have exactly the same shape as the exciting current curve has, when the current drawn from the sine wave generator is only that due to the transformer, the secondary of which is open.

It has been suggested that we should know the relations between the ultimate strength and the elastic limit in insulating materials. The insulation engineer has a very difficult problem to handle. With low voltages it is fairly simple; but when we get up to the higher voltages, there arises a new order of affairs. One of the things to guard against particularly is that we do not

encounter unawares a new kind of phenomenon. For example, when we test at two or three times normal voltage, we are simply endeavoring to determine the breaking down strength. Some new phenomenon like dielectric hysteresis may come in to produce heating, or in suddenly applying the voltage for test there may be some sudden rise of voltage which was not anticipated. It is things of this kind, these incidental and unexpected things, which we must guard against particularly.

Mr. Thomas:—I will take only a moment or two. The building and testing of high-tension apparatus, transformers or generators, is an extremely intricate and complicated problem, and no person who has not worked on a design and used such material can have any real appreciation of the difficulties involved. These criticisms and recommendations, if we may call them such, which I have drawn up here, are based on a very long line of experience, tests, actual apparatus troubles, and represent a very careful consideration of all the data.

Mr. Peck began by calling attention to the fact that the apparatus is likely to get strains on layers near the terminals of the transformers during the early testing of the line and that tests ought to be made in apparatus purposely to apply these strains. This would certainly be very desirable on the face of it, and is desirable if it can be carried out practically. But this great difficulty is met; Suppose you make the test and our transformer fails to stand it. You can't always know the fact. A spark occurs between two layers inside somewhere, and since the apparatus is, in all probability, not in a position to be supplied with generator current to the full capacity of the system, your insulation is punctured, the spark passes and ceases, stops, and you think the transformer is all right. You go ahead and a little later a strain of much less magnitude comes along and when conditions are favorable for that fault to be developed, and the general apparatus breaks down. That is one of the difficulties.

[Contributed after Adjournment by Dr. Louis Bell.]

I do not think it wise for a purchaser of apparatus to place much reliance on over-voltage tests set forth in contracts, save in the case of line insulators, switching and such-like simple apparatus. In other cases such tests ought not to be long continued, and should not be made until the apparatus has successfully stood a full load test and recovered therefrom. Then a moderately severe over-voltage test can be usefully applied, merely to try out the insulation as a whole. I do not concur that a disrupture test is unfair because it may subject to severe strain parts of the insulation which normally receive in commercial working only a moderate strain. The disrupture test ought to try out these very points, for danger to insulation from minor lightning discharges, resonance and the like frequently catches apparatus at just these weak points, since trouble usually comes from abnormal, not ordinary, conditions. Personally, I

attach some value to an overload test at a voltage somewhat greater than will ever be demanded in practice, with careful insulation measurements before and after.

[CONTRIBUTED AFTER ADJOURNMENT BY MR. P. G. GOSSLER.]

The grounded wire method of protection against lightning has been used on the transmission lines of the Montreal Light, Heat & Power Company for the last four years, with very satisfactory results. For three years the transmission lines were operated at two-phase, 12,000 volts and for the last year at 3-phase, 25,000 volts.

The 2-phase transmission lines consisted of duplicate lines run from Chambly to Montreal, the total distance being about 17 miles for each line of which 14½ miles were ærial and 2½ miles single-conductor rubber-insulated underground cables. The underground cable was divided up in three sections, the first section was about a mile and a half from power house, the second about 15 miles from the power house, and the third at the Montreal end.

The present transmission lines consist of duplicate lines, 17 miles for each line of which 15½ miles is ærial, and 1½ miles underground cables at one end. Three lines of barb wire are run on pony glass insulators on each pole line, two lines being run on the ends of the top cross-arms 32 inches from the line wire, and the third on a pin on the top of pole.

The barb wire is composed of two twisted No. 12 B.W.G. galvanized iron wires with one four point barb every five inches, and is connected at each pole by means of a soldered joint to the ground wire. This ground wire is stapled down the face of the pole and is twisted several times round the butt, after running through an iron pipe about 8 feet long, which projects above the level of the ground, preventing the wire from being cut or broken, as well as affording an additional ground.

As the poles are set 90 feet apart the barb wire lines are grounded about fifty-eight times per mile; this frequent grounding being one of the most important points in the protection.

It has been the general opinion that ordinary barb wire lacks good mechanical properties, is liable to corrosion and to cause interruption to the service by breaking and becoming tangled with the transmission wires.

This has not been our experience. In the line described above, ordinary commercial barb wire was used and we have only experienced two cases of the barb wire breaking. In both cases it fell clear of transmission wires and did not become entangled with the conductors. We are of the opinion that our freedom from mechanical troubles has been due to the care exercised when stringing the line, and also fastening to a glass insulator, instead of stapling to the cross-arms and top of poles.

We also use the Westinghouse low equivalent a.c. lightning arresters, in conjunction with the barb wire. Banks of arresters being located at both ends of the ærial lines.

We have undoubted proof of the usefulness of barb wire protection as applied to our system. The first year and a half of operating our 12,000 volt Chambly Plant we did not have any protection against lightning but the barb wire. The first summer we had the opportunity of watching the effect of a very severe storm which traveled from Montreal to Chambly, passing over the district through which our transmission lines run; this storm did considerable damage in Montreal, shattered several trees along the transmission line, and also damaged the local lines in Chambly, but no trouble was experienced on the transmission lines.

So satisfied are we of the usefulness of barb wire as a protection that we have installed it on many of our local 2400-volts circuits in and around Montreal, with satisfactory results.

A paper presented at the 20th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, July 1st, 1903.

CHOICE OF FREQUENCY FOR VERY LONG LINES.

BY P. M. LINCOLN.

Although other frequencies are in use in this country, there are only two which by the extent of their use can be called standard, viz.: 60 and 25 cycles per second. Without discussing the relative merits of other frequencies, the question now presented is, which is the better frequency for a very long line, 60 or 25 cycles per second, considered purely as a transmission problem.

In the present state of the art, 200 miles may be considered as very long for a transmission line. Although longer ones have been proposed, only one of this length has been put into actual operation and no other line approaches this length. The reasoning which follows will, therefore, be made to apply to a typical line 200 miles long.

Frequency has a direct bearing upon voltage regulation and charging current and its influence on a possible condition of resonance may also be profitably discussed.

1st. *Voltage Regulation.*—The difference between the voltage at the transmitting and the receiving stations, termed the "drop," is dependent upon several elements, among which are the resistance and the inductance of the circuit. The volts for overcoming the resistance are the same as would be required for sending a direct current equal to the normal alternating current through the line, if it be short-circuited at the receiving end. The volts for overcoming the inductance at any frequency are measured by the pressure which would be required for sending the alternating current at that frequency through the short circuited line, if the ohmic resistance were negligible. The inductance volts are directly proportional to the frequency. The difference in voltage between the transmitting and receiv-

ing stations, or the " drop," is a function of the resistance volts, the inductance volts and the power factor of the load.

Consideration of voltage regulation at the receiving end limits, according to best practice, the resistance volts in a transmission line to about 15 per cent. as a maximum, and the same consideration should keep the inductance volts within a maximum of 20 per cent. This will mean a line regulation of about 24 per cent. with a load power factor of 85 per cent. Best economy may reduce the resistance element below the maximum given. The resistance volts may be reduced to any given amount by the addition of copper, while inductance volts are little affected by increasing the size of wire. An increase in size of conductor which will reduce resistance volts by one-half will reduce inductance volts only about 5 per cent. The matter of inductance volts, therefore, constitutes a limit to the amount of power that can be delivered over a single line. This consideration will limit the amounts of power which can be delivered by a three-phase line 200 miles long to approximately the following:

TABLE SHOWING LIMITS OF TRANSMISSION LINE CAPACITIES.

Voltage at Receiving End. 200 Mile, 3-Phase Line.	Power Delivered with 20% Inductance Volts.	
	60 Cycles.	25 Cycles.
20,000 Volts	500 k.w.	1,250 k.w.
30,000 "	1,125 "	2,800 "
40,000 "	2,000 "	5,000 "
50,000 "	3,125 "	7,800 "
60,000 "	4,500 "	11,250 "
80,000 "	8,000 "	20,000 "

For longer or shorter lines the k.w. in the above table may be decreased or increased in direct proportion.

If the amount of power to be transmitted is large, the multiplication of lines necessary at 60 cycles unduly increases expense both of pole lines and of right of way for same. This point is evidently in favor of the lower frequency.

2d. *Charging Current.*—Charging current is, of course, a direct function of frequency and voltage and to a slight extent of line construction. At 60 cycles the apparent energy represented by the charging current in a 200-mile three-phase line is practically equal to the ultimate capacity of that line as limited by the 20 per cent. inductance volts consideration. At 25 cycles it is only about 15 per cent. of the ultimate capacity as limited by the same consideration. In a 60-cycle installation,

therefore, it is necessary either to operate the generators on such a line at about full current output all the time, no matter what the load, or to compensate for the charging current in part or in whole by the installation of choke coils, either horn of which dilemma is not pleasant to consider. The problem of taking care of the charging current at 25 cycles does not enter the discussion as compared with 60 cycles.

The effect of a large charging current on the regulation of the generator should also be considered. As is well known, a line charging current, when circulating in a generator armature, has the effect of assisting the field ampere turns to magnetize the fields. The percentage of magnetizing done by this charging current depends upon its amount and the inherent regulation of the generator. Since the charging current depends upon the voltage, the generator exciting power of the charging current also depends upon the voltage. The effect of sudden load changes, therefore, which tend to change the voltage delivered, will in turn affect this element of the excitation. That is, to a certain extent, the generator assumes the regulation which inherently belongs to a d.c. shunt generator. The effect of large charging currents on generator regulation is, therefore, not toward an improvement.

3d. *Resonance.*—As is well known, every combination of a condenser and choke coil in series has a natural period of oscillation, whose value depends upon the square root of the product of the condenser capacity by the choke coil inductance. If a frequency of its natural period be applied to such a combination, resonance will occur. That is, a small exciting force of the proper frequency will cause comparatively large currents to circulate between the condenser and the choke coil and therefore comparatively large voltages across both the condenser and choke coil. This is an example of resonance in its simplest form.

A transmission line possesses both capacity and inductance, and therefore the possibility of becoming resonant under certain conditions. The fact that both the capacity and inductance of a transmission line are distributed throughout its entire length, and the disturbing effect of concentrated inductances and capacities at transmitting and receiving stations, makes the problem of determining under what conditions resonance will occur an extremely intricate one. A first approximation may be obtained, however, by assuming that the inductance and capacity of a line are concentrated instead of distributed, and omitting the

effects of translating devices. Under this assumption, we may consider that the capacity of a distant portion of the line is in series with the inductance of the intermediate portion.

The natural period, that is, the applied frequency at which resonance will occur between the parts of a transmission line, will be a minimum when the two parts are equal, or each is equal to one-half the total line. The number of natural periods above this minimum is infinite, since it is possible to divide the line into two parts, the inductance of one of which multiplied by the capacity of the other may be any quantity less than that obtained by dividing the line into two equal parts.

The minimum period of a 200-mile line is approximately 200 cycles per second. There is, of course, no danger that the fundamental applied frequency will produce resonance until the length of line largely exceeds 200 miles, but the same cannot be said of some of the harmonics if they are sufficiently prominent. The lower the fundamental frequency, the less is the danger from this source. So far as the writer is aware, no actual trouble has ever been experienced in existing plants from this source even on the longest lines and highest frequencies in use, but it nevertheless constitutes an advantage for 25 over 60 cycles that cannot be dismissed with a scoff.

It is a fact that the longest transmission line in the world—the Bay Counties line in California—as well as the highest voltage line—the Missouri River Power Company in Montana—are both operating at 60 cycles. These facts, however, do not detract from the force of the preceding reasoning.

It is not claimed that this discussion contains all of the arguments pro or con. The bringing out of additional points as well as the soundness of those presented, is left to the discussion which it is hoped the above will provoke.

MR. B. A. BEHREND:—Mr. Lincoln's figures indicate clearly that, with a given amount of material in a long line, more power can be transmitted at 25 cycles than at 60 cycles. Mr. Lincoln calls attention to the possible danger of resonance as produced by the higher harmonics superimposed upon the fundamental used for the transmission. Mr. Lincoln says: "The fact that both the capacity and inductance of a transmission line are distributed throughout its entire length, and the disturbing effect of concentrated inductances and capacities at transmitting and receiving stations, makes the problem of determining under what conditions resonance will occur an extremely intricate one. A first approximation may be obtained, however, by assuming that the inductance and capacity of a line are concentrated instead of distributed and omitting the effects of translating devices."

I showed in a brief contribution to M. Leblanc's paper at the Convention of the INSTITUTE last year that the natural period of oscillation of a transmission line with distributed capacity and self-induction can, without difficulty, be calculated. The method in my contribution requires no extraordinary mathematical knowledge beyond simple differential equations, and I have shown on page 1213 of our volume XIX of 1902 that the fundamental of the natural frequency of oscillation of the line is:

$$\frac{1}{4 l \sqrt{L C}}$$

while the natural frequency, if we assume the capacity and self-induction to be concentrated, is equal to,

$$\frac{1}{2 \pi \sqrt{L_1 C_1}}$$

The discharge frequency of a long line with distributed capacity and self-induction is, therefore, greater than if the capacity and self-induction were concentrated.

Although this is all very interesting, I feel somewhat skeptical about the practical importance of this resonance. It may be possible that such resonance occurs on long transmission lines, but I should prefer to suspend judgment on this point until the facts had forced themselves upon my attention. I cannot help thinking of the unreasonable importance which at one time used to be attributed to the wave-form of alternating current generators a case which has almost entirely broken down. But, at one time, the wave-form was the scapegoat for all sorts of mistakes made and a perfect bugbear to the designing engineers.

In considering the question whether a frequency of 25 or 60 cycles is preferable for power transmission purposes, we should not confine our attention to the line itself, but we should take

into consideration the generating plant, the transformers and the substation as well. In regard to the generating plant and the transformers, there can be no doubt that a frequency of 25 is rather lower than desirable. In regard to the substation apparatus, a frequency of 25 is as high as desirable for rotary converters, while it is too low for lighting. Is not, after all, then, Mr. Lincoln's problem the same that has been argued for fifteen years, viz., the problem of the most favorable frequency?

I may add to Mr. Lincoln's statement to the effect that the longest lines, as the Bay Counties and the Missouri River, are operated at 60 cycles, that the first long distance transmission line of 115 miles in length between Lauffen and Frankfort, which was built in 1891, was operated at a frequency of 50.

MR. F. G. BAUM:—The first criticism I have to make on this paper is that it confines the discussion of the choice of frequency to the transmission line.

Unquestionably, so far as the line is concerned, the lower the frequency the better the regulation, and the greater the capacity of the line, limiting the capacity of the line by the inductive volts. But the fallacy of reasoning that a low frequency is, therefore, to be used, becomes immediately evident if we pass to the transformers, where the higher the frequency, the smaller the weight and cost, and the greater the efficiency.

The best frequency for the generators is, of course, dependent upon the speed at which they are driven, and on their capacity. With slow speed engines, low cycles would no doubt be preferable, but in water power plants, operating at speeds from 300 to 500 r.p.m., with peripheral speeds of about 10,000 feet per minute, according to the head of water used, the best frequency for the generators will be higher than when driven by low speed engines.

A power company at the present time, in California at least, if it is to be a success, must sell a good proportion of its load to small towns for lighting, etc. These towns being already equipped with 60 cycle apparatus, practically force the power companies to supply that frequency.

As to the limits of the percentage of resistance pressure or copper loss, I believe 15 per cent. as a maximum is a little high, and a satisfactory system should probably not have over 10 or at most 12 per cent. The limit of 20 per cent. for the reactance pressure is, I think, a little low.. As it is possible generally to have pretty fair control of the power-factor of the line, a maximum of 30 per cent. for the reactance pressure would, I think, not be excessive, and would give satisfactory service.

The charging current is not difficult to handle. If the load is to be mostly induction motors, the charging current will improve the power-factor of the generators. However, a 30 cycle system would be better than 60 cycle so far as handling the charging current is concerned.

Undoubtedly if our lines are to increase in length to 300 and

up to 500 miles, we must operate at less than 60 cycles, in order to reduce the reactance volts and also on account of coming into resonance with the line.

PRESIDENT SCOTT:—This paper is another example of what was referred to this morning in another connection; namely, the new class and order of phenomena which may appear when the voltage is changed. The various points which have been taken up in this paper; namely, regulation, charging current and resonance, have little or nothing to do with the choice of frequency at low voltages. For instance, in an installation of an isolated plant, or one for short distances, in which the voltages are not more than a few thousand. But when the higher voltages and the longer distances come in, then these new problems appear; new elements have very great importance, sometimes they are even the limiting conditions. The subject is one which is open now for general discussion.

MR. MAILLOUX:—It seems to me that in a matter of this kind the consulting engineer is confronted more by conditions than by theories. If he has to consider locations where the electrical energy is to be used principally for lighting, he must of necessity adopt a frequency that will be compatible with satisfactory lighting. In all the cases which I have had to deal with in long-distance transmission thus far, that condition has been imposed by the facts and circumstances of the case. It has been necessary to make provision for a current capable of giving satisfactory lighting, because the bulk of the current was intended to be used for that purpose. Now the question it seems to me, therefore, would be, in striving to obtain a compromise between extremes, to determine what is the minimum frequency that is satisfactory for lighting purposes. Experiments have been made with the various frequencies in Europe. There are many plants which are furnishing or attempting to furnish lighting current with frequencies as low as 40. I have seen several of those plants, and I must say that I do not consider them satisfactory. One can see stationary objects very well, but moving objects seem to have a jerky motion which is unpleasant and even annoying. I would like to know if any of the gentlemen present have had experience with frequencies as low as 50. It has occurred to me several times that perhaps a frequency of 50 might be a satisfactory compromise. We all know that 60 is perfectly satisfactory for lighting, but it would be very interesting to know what experience has been had with frequencies lower than 60, in this country.

MR. STOTT:—As to the frequency at which incandescent lighting becomes impossible, I think that point comes at just about 20 cycles, from some experiments which have been carried out. Twenty-five cycles, with a low efficiency lamp, taking about 4 watts per candle, and with a voltage not to exceed 110, where the filament is comparatively heavy, is quite satisfactory. We have tried the experiment of having direct current lighting in

the draughting room and then without notice throwing it over on the alternating current, and no one knew anything about it; and this certainly demands the best light possible.

PRESIDENT SCOTT:—You are using it in the elevated stations in New York.

MR. STOTT:—Yes; we have about 30,000 incandescent lamps run now on 25 cycles, and very few people notice the fluctuation. I think it depends a good deal upon the voltage regulation and also upon the fact that low efficiency lamps are used.

MR. MAILLOUX:—How about the Nernst lamp?

MR. STOTT:—I have no information about the Nernst lamp. I understand 25 cycles is rather low for it. In reference to the general proposition of frequency, it seems to me that it is a local condition which must be considered in connection with every individual proposition, which is brought up.

MR. MERSHON:—Mr. Lincoln considers his subject purely as a transmission problem. It is not very often that you get a chance to consider the engineering of transmission from that standpoint. You generally have to take into account certain conditions that have to be met. You cannot select the frequency of your apparatus just as you choose. Now, in many of these cases—I guess it has been true of all the California plants—I think it is true of most all the transmission plants that have been put in—the condition to be met first was that of delivering power at 60 cycles. The transmission enterprises could not have existed, probably, if you had insisted on putting in the 25 cycles, in that there would not have been enough immediate prospective market to have made it possible to finance the enterprise, and in order to get this market, and get it as soon as the plant was in operation, it was necessary to deliver 60 cycles. In such a case, the question comes down to whether or not it is better to transmit at 25 cycles and use frequency changers for 60, or whether it is better to transmit at 60 cycles and use synchronous motors to raise the power-factor of your load, or even bring up the drop in your line to approximately that of the copper drop. If you consider the question of the investment in these cases, you will find that the 60 cycle plant shows up much more favorably. Take, for instance, the use of motor generators for changing your frequency from 25 to 60 cycles—you would require, with a power-factor of 85, which is the one Mr. Lincoln has taken, approximately 220 per cent. in actual machine capacity, counting both motor and generator, and the fact that your generator has got to be able to take care of a power-factor of 85. If you are using synchronous motors and bring your power-factor up to unity, it will require about 53 per cent. Now, that represents not only the cost of the machines, cost of the switchboard apparatus for handling them and cost of station room for installation of machines, but in addition to that there is the question that has been mentioned of the less cost of the transformers for 60 cycles. As regards the question of the charging current on 60 cycles, if synchronous motors

were used, you would be able to get a greater amount of power over a single line than Mr. Lincoln has calculated. Besides, you could reduce the effect of the capacity current on the generator by means of these synchronous motors, by keeping some of them running at light loads just as you would have to do in case of frequency changes. I cannot see that the capacity current of the line will seriously affect the generator regulation. The generator excitation depends upon ampere-turns either in the field winding or the armature winding. To the over-excitation, required to neutralize the armature-reaction of a given lagging load, is due, mainly, the rise in voltage when such a load is thrown off. If the same lagging load be carried but in conjunction with a charging current, such as brings the power factor at the generator terminals to unity, the unity condition is due to the fact that the reaction component of the lagging load has been neutralized by the charging current. When, therefore, the lagging load is thrown off, there is left on the generator the charging current whose effect on the generator magnetization is about equal to, in fact somewhat less than, that of the over-excitation previously referred to. True, the rise of voltage tends to increase the charging current which in turn tends to increase somewhat the voltage rise, but this cumulative action will be held in check by the fact, just referred to, that ampere-turns in the armature are less effective in raising voltage than an equivalent number of ampere-turns in the field.

As regards the question of frequency in lighting, I think there is an element to be considered that has not been mentioned, namely, personal peculiarities. I have tried in a number of cases to find out the impression made on different people by low frequency lighting. At 25 cylces, if I endeavor to do so, I can notice a flicker in any 25 cycle installation I have ever seen, but it does not bother me. Some people say that it annoys them at all times, and some people say that they can even see the flicker in the case of frequencies considerably above 25 cycles. I think, however, that the majority of people cannot notice any effect from 30 cycles. Possibly they could with quick movements of illuminated objects, but I do not think that with the ordinary movements of every day life they would notice any flicker at 30 cycles.

Mr. Rushmore:—An interesting instance came to my notice some time ago in talking with an engineer of one of the large transmission systems. On some of their new lines, he said that they were using a maximum distance between wires for the purpose of obtaining the greatest possible line inductance, the rise in voltage being greater than was desirable.

The form of e.m.f. curve has been mentioned as being something about which we need at present concern ourselves but little. This is quite opposed to my own view. The capacity charging currents on these high voltage lines very considerably amplify any harmonics which may exist in the original wave.

Under such conditions, it is necessary that the wave form approximate closely that of a sine function. In modern generators this is the case, which perhaps explains to some extent the reason why but little is heard on the subject.

Mr. Lincoln:—Mr. Mershon advanced the idea that synchronous apparatus could be operated at the receiving end of the line to compensate for the inductive drop. I wish to take issue on that point. It is possible so to operate synchronous apparatus that the current at the receiving end of a transmission is either lagging or leading with respect to the e.m.f. at the will of the operator. That is, the inductive "drop" in the transmission may be made to subtract from or add to the generator volts at the will of the operator. This fact, however, is not going to help line regulation, that is the change in receiving end voltage for a given load change—unless the field strength of the synchronous apparatus can be changed automatically with load. The limiting factor in very long lines is regulation and I do not see how Mr. Mershon's scheme of putting synchronous apparatus at the end of the line helps regulation. And for the same reason I would differ from Mr. Baum where he places the real loss in a transmission line at somewhat less than I have. I have placed it at 15 per cent. He says it is not over 10 per cent. or 12 per cent., and he places the inductance drop at 30 per cent., instead of 20 per cent., as I had it. That inductance drop is going to have an important influence in the regulation of the line, and if we are going to limit our regulation to 25 per cent., I don't see how you are going to allow 30 per cent, inductance drop, particularly with loads of low power-factor.

Mr. Mershon:—I cannot quite agree with Mr. Lincoln. The action of a synchronous motor with a constant excitation is similar to that of a condenser so long as the voltage impressed upon the motor does not vary, but as soon as the voltage begins to vary the similarity ceases. If the voltage rises on a condenser the condenser takes more current. If the voltage rises on an over-excited synchronous motor the motor takes less current. The voltage may rise to a point where the motor will take practically no current or it may increase to a point enough greater than this so that the motor instead of taking from the line a leading current, it will take a lagging current tending to pull down the voltage, or rather, limit the rise. The action of the idle synchronous motor is therefore corrective which a condenser would not be. This corrective action of a synchronous motor will depend for its amount on the inherent regulation of the motor. If we chose to go to extremes we might make the synchronous motors dominate the system completely as regards the delivered voltage and might keep the voltage variation as low as we pleased by employing motors with very low inherent regulation.

Dr. Perrine:—I would like to say that whether it is possible or not to regulate a line with a synchronous motor as the last speaker describes, it has never been done; but the

regulation of the line by means of an automatically excited synchronous motor has been done and was described by Mr. Baum in his paper presented before the meeting last year, where he showed how he regulated by means of an automatic exciter the voltage of the Bay Counties line at Oakland, overcoming the effect of capacity and inductance on the line by means of synchronous motors.

MR. H. A. STORRS:—If the discussion need not be limited to 200 mile lines, there are one or two points which might be of interest. First, as regards the highest frequency which will produce a noticeable flicker in the lamp. A number of years ago in the laboratory at Columbia College we had a small rotary converter which was under control so that we could produce alternating currents of any frequency we desired, and we made a good many tests with 15 or 20 students at a time, in order to determine what frequency could be detected. The condition is quite different from what it is to go where a system is being operated at 25. You know the frequency, and you look at a lamp, and you say, yes; you can see the flicker of the light. But if you start with a high frequency and gradually lower it, telling everybody to keep his eye on the lamp, different men will at different instants say that they detect a flicker; and if, as you repeat that experiment, the same man detects a flicker repeatedly at the same frequency, why that is pretty good proof that he does detect the flicker. Under other conditions there is a good deal of imagination about whether you detect the flicker or not. As a result of a good many experiments of that kind, with lamps of various efficiencies, we found that 20 or 21 was about as high a frequency as any man could detect repeatedly. In fact, the majority could not detect a frequency of 20.

PRESIDENT SCOTT:—I would like to call attention to one thing. We are here dealing with certain engineering problems. We have a paper here which deals with the engineering question. What are the factors in connection with a line, a very long line, which bear on the determination of frequency; and we have gotten off from that into a whole lot of commercial things which have nothing to do with this question. What have incandescent and arc lamps to do with this? Mr. Lincoln has shown us here that certain facts prevail if we want to transmit at 50,000 volts, 200 miles. If we get beyond 3,000 kilowatts, we are going to exceed certain engineering limits which he has assigned, and he has done well to call our attention to those things, and bring them in as an engineering problem. The specific application will come in somewhere else.

MR. MERSHON:—Mr. President, will you allow me to take issue with you in six words.

PRESIDENT SCOTT:—In a moment. I call attention to this at this time, so that in this discussion we may endeavor to keep in on the plane of engineering rather than commercialism; not that the commercial is not important, but that the other is the important thing here. Now, in six words, Mr. Mershon.

Mr. Mershon:—It seems to me that if you confined this question of frequency to the transmission line alone, there would not be any discussion. We would agree on the 25 cycles or perhaps on direct current. It seems to me that an engineering problem is always more or less commercial. A physical problem is not an engineering problem until it is commercial; it is simply scientific.

A paper presented at the 20th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., July 1st, 1903.

Y OR Δ CONNECTION OF TRANSFORMERS.

BY F. O. BLACKWELL.

The two alternative methods, Y or Δ, of connecting transformers to a three-phase system, come up for discussion with every three-phase installation. A general statement of the advantages and disadvantages of both connections, as they appear to the writer, is given here with the hope that those engineers who have had most experience with power transmission will contribute their views on the subject.

TRANSFORMERS.

Assuming that three transformers are to be used for a three-phase power transmission, and that the potential of the line is settled, each of the transformers, if connected in Y, must be wound for $\frac{1}{\sqrt{3}}$ or about 58 per cent. of the line potential, and for the full line current. If connected in Δ, each transformer must be wound for the line potential and for 58 per cent. of the line current. The number of turns in the transformer winding for Y connection is, therefore, but 58 per cent. of that required for Δ connection and the cross section of the conductors must be correspondingly greater. The greater number of turns in the winding, together with the insulation between turns necessitates a larger and more expensive coil for Δ connection. The larger coil calls for a longer magnetic circuit and consequently a larger and heavier transformer throughout. This is of no importance when the potential of the coil is low or when the transformer is large and the current high. In fact, in transformers in which the current is heavy it is usual to divide the conductors into several multiple circuits for ease of handling and

to avoid eddy current losses that occur when the cross section of the conductor is too large. A few turns more or less in the winding under such conditions is, therefore, immaterial.

In transformers of small capacity wound for high potential, the cost and weight are both considerably in favor of the Y connection of the high potential coils.

Where it is desired to secure the smallest transformers that can be wound for any given potential, the minimum size of wire that can be employed in the windings of the high potential coils and give sufficient mechanical strength, is the limiting feature. A transformer practicable for Y connection may be smaller therefore than can be commercially considered for Δ connection.

The Y connection requires the use of three transformers, and if anything goes wrong with one of them the whole bank is disabled. With the Δ connection, one of the transformers can

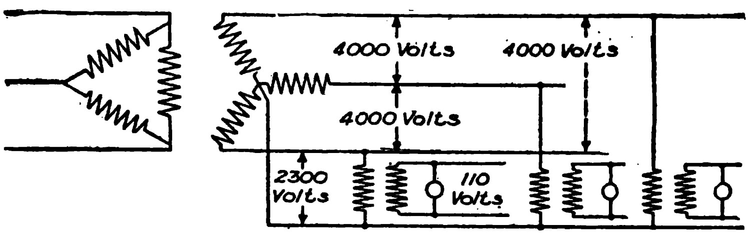


Fig. 1 Step Down Transformer For 4000 Volt Y Distribution

be cut out and the other two still deliver three-phase power up to their full capacity; that is, two-thirds of the entire bank.

Combined three-phase transformers are generally of small size and on that account are preferably Y-connected on the high potential side.

GROUNDING THE NEUTRAL.

If the common connection of transformers joined in Y is grounded, the potential between windings and the core is limited to 58 per cent. of that of the line, and the insulation between the windings and core might be proportionally reduced. The same argument applies to the transmission circuit and would allow the size of the line insulators to be reduced.

The saving that can be made in insulating transformers by grounding the neutral is not great with large transformers, but is important on small ones, as the space taken up by the insulation for any given potential is relatively greater in a small

transformer. Under normal conditions, the potential between any conductor of a three-phase transmission circuit and the ground is 58 per cent. of the line potential, with either Y or Δ connection, but the neutral may drift so as to increase the potential with an ungrounded system. If one branch is partly or completely grounded, the potential between the other two branches and the ground is, of course, increased and may be the full line potential. With a grounded neutral Y system, a ground is a short circuit of the transformers on the grounded branch and the transmission becomes inoperative.

From the point of view of safety to life and prevention of fires this is a desirable condition, especially if the low tension distribution is also grounded. If the high tension circuit makes contact with the ground or low potential system, it can be immediately cut out by fuses or automatic circuit breakers.

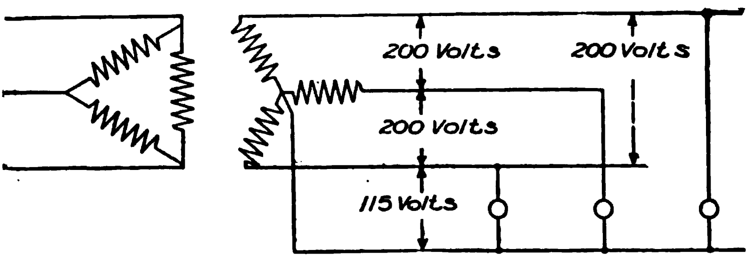


Fig. 2 Step Down Transformer For 200 Volt Y Distribution

The difficulty is that a power transmission with grounded neutral is likely to be frequently shut down by temporary grounds, such as would be caused by a tree blowing against one of the wires. Even if the circuit is not opened, the drop in the pressure due to the sudden " short " on the line will cause synchronous apparatus to fall out of step. Under the same conditions a system without a grounded neutral would give uninterrupted service.

Unstable Neutral.

If two transformers are connected in series, there is no certainty that they will divide the potential equally between them. A system in which all the electrical apparatus is connected in Y has somewhat the same characteristics. The neutral may drift out of its proper place and there will be unequal potentials between it and the three conductors of the circuit, due to unequal loading and differences in the transformers or transmission cir-

cuits. Such unbalancing would cause unequal heating of the transformers and if a four-wire three-phase system of distribution were employed, would seriously interfere with the regulation of the voltage. In transformers, therefore, have Y secondaries, it is desirable that the primary should be △ connected. Two systems in common use with which △ primary windings should be used, are shown in Figs. 1 and 2.

Rise of Potential.

The high potential windings of transformers are necessarily of high reactance, and if left in series with a circuit of large capacity, as shown in Figs. 3, 4, 5 and 6, the leading charging current flowing over the reactance may set up extraordinarily high pressures. Figs. 3 and 4 represent Y connected banks of three transformers, each connected so as to cause such a rise of potential. In Fig. 3 the primary of one trasformer is excited by a generator, the primary of the other two transformers being

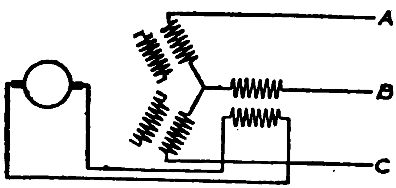


Fig. 3

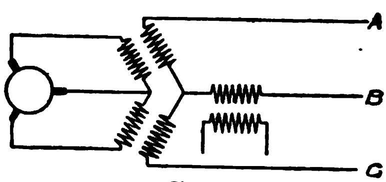


Fig. 4

open-circuited. In Fig, 4 the primary of one transformer is open circuited, the other two being connected to the generator. Figs. 5 and 6 show T connected banks of two transformers, which might be used to transform from either two-phase or three-phase to three-phase or vice versa, and are similar in action to Fig. 3. If in any one of Figs. 3, 4, 5 or 6 the secondaries are connected to a long distance transmission circuit, a pressure of many times the normal potential will be set up between A and B, and between B and C, that between A and C not being affected.

It is theoretically possible for a potential 100 times that for which a transformer is wound, to be caused by opening the primary switches of one or more of the transformers of a bank connected in Y before the secondary switches are used. Of course, actually, the current jumps across the insulation at some point in the system before there can be any such increase in pressure. If there are a number of banks of transformers in parallel, this phenomena cannot occur except when all but one

bank are disconnected. This source of trouble could be obviated by employing oil switches on the high potential side which disconnect the line before the low tension switches are used, or by triple pole switches on the primary which open all three branches of the bank of transformers at once.

The selection of Y or △ connection of transformers for long distance transmissions should only be determined after a careful consideration of the conditions in each case.

There is little choice between Y or △ without a grounded neutral.

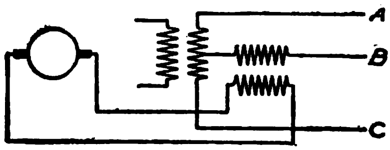


Fig. 5

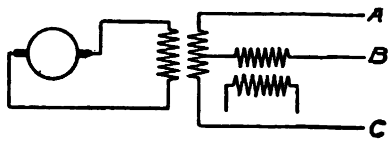


Fig. 6

In small installations, the cheaper cost of transformers for Y with a grounded neutral will be a determining factor. Larger plants will be guided by the greater importance of giving uninterrupted service and will not employ a grounded neutral unless demanded on the score of safety.

Where the amount of power is great and the system extensive, △ connection will be generally preferred on account of its avoiding the possibility of rises of potential from any cause. Many plants can have advantageously a mixed system with both Y and △ transformers, each installation of transformers being considered by itself.

[CONTRIBUTION TO DISSCUSSION ON F. O. BLACKWELL'S PAPER BY J. S. PECK.]

MR. J. S. PECK:—In his paper, " Star or Delta Connection of Transformers," Mr. Blackwell refers to the grounding of the neutral points of a transmission system, for the purpose of limiting the strain between line wires and ground, and mention is made of the fact that the neutral point is likely to drift out of position and cause unequal voltage strains upon different parts of the circuit.

The question of grounding or not grounding the neutral and of the best method of connecting transformers is one of great importance, and it is the object of this paper to point out some of the conditions, both normal and abnormal, which arise with different systems of connections with and without grounded neutral.

By the grounding of the neutral point of a transmission system it is sought:

First:—To limit the strain from line wires to ground.

Secondly:—To limit the strain between high-tension and low-tension windings of the transformers, also between high-tension windings and iron core.

There are a number of different ways of connecting transformers for transmission work:

Single-phase, 2-phase, 3-phase-delta, 3-phase-T, 3-phase-V 2-phase-3-phase, 3-phase-star, 3-phase-star-and-delta.

Consider first the case of a single-phase transformer ungrounded, with high-tension and low-tension voltages taken for convenience as 10000 and 1000 respectively, (see Fig. 1). There is evidently a maximum strain of 10000 volts from one high-tension line wire to the other. If the circuits are insulated and symmetrical there will be a strain of 5000 volts from each line wire to ground, and from each extremity of the high-tension winding to the low-tension winding and to the iron core.

If, however, the circuits are not symmetrical, the full strain will not be equally divided, and if in an extreme case one high-tension wire is grounded there will be a strain of 10000 volts from the other line wire to ground; similarly, if one extremity of the high-tension winding be connected to the low-tension winding or to the core, there will be a strain of 10000 volts from the other extremity of the high-tension winding to the low-tension winding or to the core.

The actual strain between adjacent high-tension and low-tension windings is equal to the high-tension voltage plus or minus the low-tension voltage, depending upon the arrangement and connection of the coils; but as the low-tension voltage is usually a small percentage of that of the high-tension, it is customary to assume that the strain between windings is equal to that of the high-tension voltage alone.

If the middle or neutral points of high-tension and low-tension windings are grounded, the iron core being also grounded (see

Fig. 2), then as long as the circuits are in balance the voltage strains will be the same as with the windings ungrounded, and balanced; but in case of a ground on either high-tension or low-

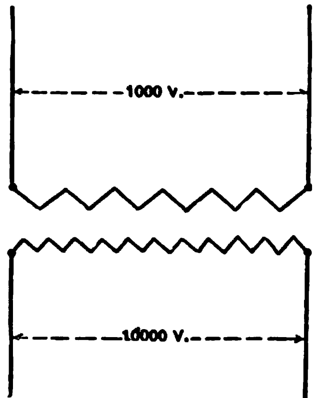


FIG. 1
Single Phase
1000 to 10000 volts
Maximum Strain to Ground
10000 volts

tension line, or in case of a connection between high-tension and low-tension windings, a portion of the windings will be short-circuited. This will, in general, blow fuses or open circuit-breakers, thus cutting the transformer out of service; or the voltage of the

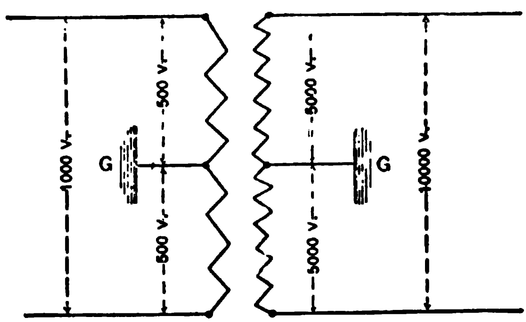


FIG. 2
Single Phase Grounded Neutrals
1000 to 10000 volts
Maximum Strain to Ground
5000 volts

system will be lowered to such an extent as to call attention to the trouble.

Thus, on a single-phase transmission system, the grounding of

the neutral point of primary and secondary windings will limit the strain from line to ground, and from either extremity of high-tension to low-tension and iron to approximately one-half the normal voltage of the system. If the neutral of only one winding is grounded, the strain from this winding to ground will be limited to approximately one-half of its normal voltage, but the strain from the ungrounded winding to ground and to iron and to the grounded winding will not be thus limited.

In considering other systems, the voltage strains between primary and secondary will not be mentioned, as these strains are easily calculated when the voltage on the transformers and the strain to ground is known. A short-circuit on a system will be assumed to cut out the trasformers.

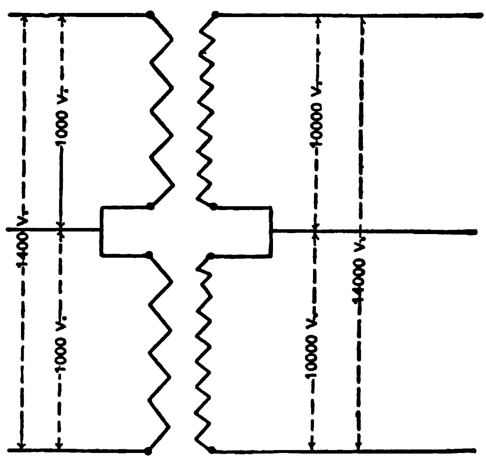


FIG 3
2-Phase - 3-Wire
1000 to 10000 volts
Maximum Strain to Ground
14000 volts

TWO-PHASE, FOUR-WIRE SYSTEM.

The 2-phase, 4-wire system is practically a double single-phase system, and the conditions for grounded and ungrounded neutral will be the same as for single-phase.

TWO-PHASE, THREE-WIRE SYSTEM.

The voltage across the two outside wires is 1.4 that between the middle and either outside wire. The connections and voltages are shown in Fig. 3, which assumes 1000 to 10000 volt transformers.

A ground on the middle wire will give a strain of 10000 volts between each outside wire and ground, while a ground upon an outside wire will give a strain of 10000 volts from middle wire to ground, and of 14000 volts from the other outside wire to ground.

The neutral point for this system may be obtained from the middle point of an auto-transformer connected across the transformer windings. In this case, a ground upon any line wire will cause a short-circuit on the transformers, thus limiting the strain to ground to approximately .7 normal line voltage.

Thus, with a 2-phase-4-wire or a 2-phase-3-wire-system, grounding the neutral limits the strain from line wires to ground, in the first case to one-half normal voltage, in the second case to .7 normal voltage.

In general, the method of obtaining the neutral point by means of auto-transformers is not feasible on high-tension systems on account of the comparatively great cost of an auto-transformer wound for the high-tension voltage, and it will not be further considered in this discussion.

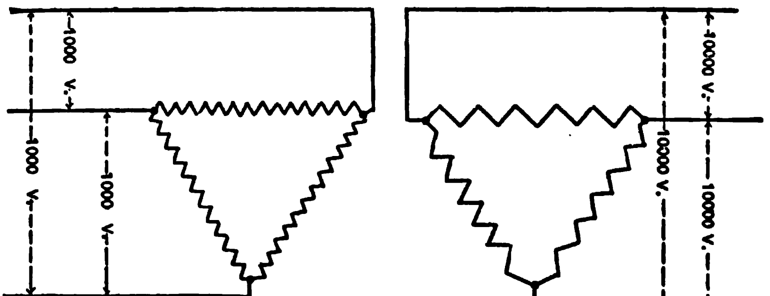


Fig. 4

3-Phase Delta Connection
1000 to 10000 volts
Maximum Strain to Ground
10000 volts

THREE-PHASE, DELTA SYSTEM.

With this system shown in Fig. 4, the strain from any line wire to ground is, with the system in perfect balance, 58 per cent. of the line voltage. In case of a ground on any line wire, the two remaining wires are raised to full line potential above the ground.

With this connection one transformer may be cut out, leaving two connected in V, and the above conditions will not be changed.

THREE-PHASE, " V " SYSTEM.

With transformers connected in V, the strains will be the same as when connected in delta.

THREE-PHASE, " T " AND TWO-PHASE-THREE-PHASE SYSTEM.

With either the T or 2-phase-3-phase connection the voltage strains with ungrounded neutral are the same as for the delta system. The neutral point may, however, be obtained from the teaser winding (see Figs. 5 and 6), in which case a ground upon any line wire will short-circuit portions of the windings.

With the 3-phase-T and 2-phase-3-phase connection the grounding of the neutral limits the voltage between line and ground to 58 per cent. of normal.

STAR SYSTEM.

With transformers connected in star the conditions are very similar to those where two transformers are connected with primary windings in series and also the secondaries in series.

Fig. 7 shows such a series combination, neutral not grounded.

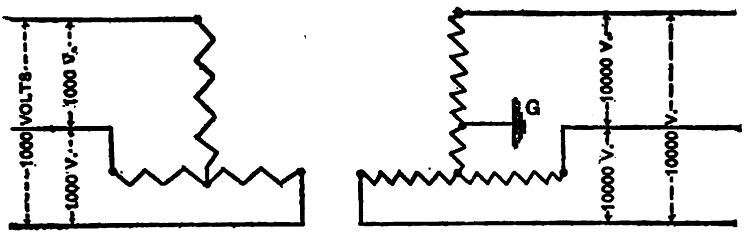


FIG. 5

Three-phase T System. 1,000 to 10,000 Volts. Neutral Grounded. Maximum Strain to Ground 5800 Volts.

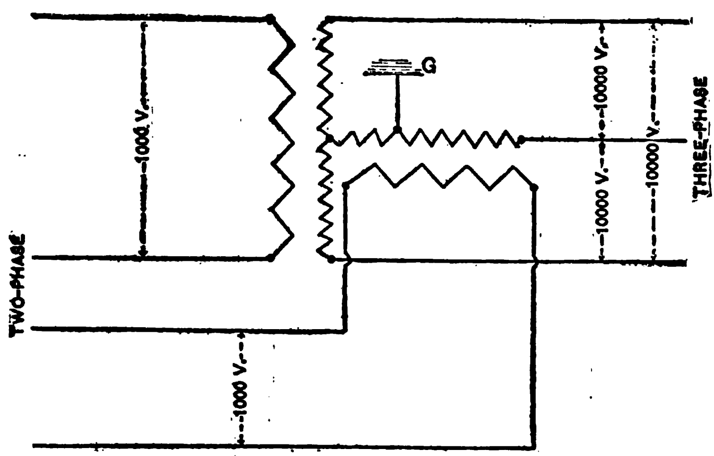


FIG. 6

Two-Phase—Three-Phase System. 1000 to 10000 Volts. Neutral Grounded. Maximum Strain to Ground 5800 Volts

The total line voltage will divide with approximate quality between the two transformers. Between line wires and ground there will exist the same strain as with a single transformer, having the same total voltage; but if one transformer be short-circuited, the full voltage will be concentrated upon the other transformer so that the internal voltage strains on this transformer will be doubled and its iron loss greatly increased, through the strain from line wires to ground may be the same as before.

If the series connection between the two transformers be grounded (Fig. 8), and a ground occur on either line wire, the transformer connected to this wire will be short-circuited and the

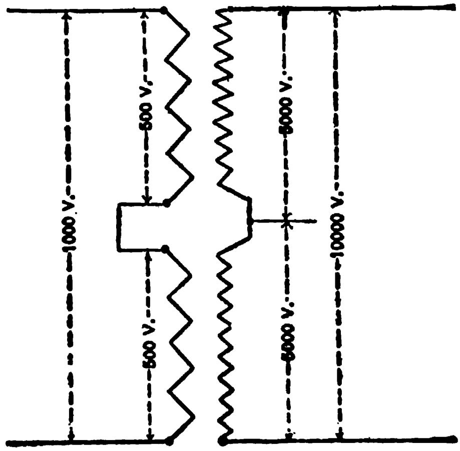


FIG. 7

Two Transformers—1000 to 10000 Volts. Primaries and Secondaries in Series. Each Transformer takes approx. ½ Line Voltage.

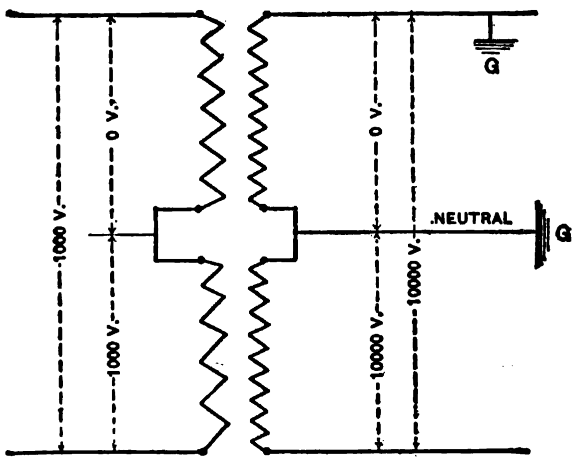


FIG. 8

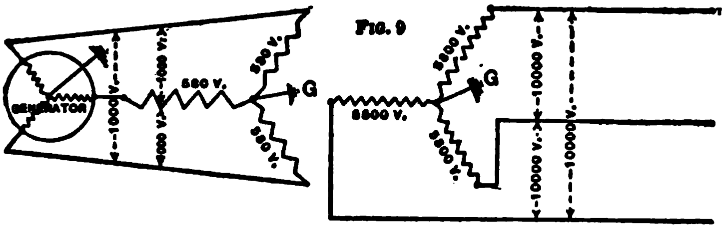
Two Transformers, Primaries and Secondaries in Series. Neutral Grounded Ground on Outside Line Wire Short Circuits Adjacent Transformer and Gives Double Voltage on Other Transformer. Full Voltage Strain to Ground.

other transformer will take the full voltage of the circuit and the ungrounded wire will be raised to full line voltage above ground. Unless the leakage current of the transformer working at

double voltage is sufficient to open the circuit, the transformer may continue to operate indefinitely under the above conditions provided it does not break down, due to excessive heating or to the double voltage strains to which it is subjected.

In Fig. 9 is shown a star-connected group of transformers with the neutral point of the primary and of the secondary, and also that of the generator, grounded. In this case no excessive voltage

FIG. 9



Three-Phase Star System. Line Voltage 1000 and 10000 Volts. Transformer Voltage 580 and 5800. Grounds on Neutrals of Generator and Transformers. Max. Voltages per Transformer 5800, Max. Voltage to Ground 5800.

age can occur on any transformer, and the strain from any line wire to ground is limited to 58 per cent of full line voltage, for a ground on any line or a short circuit in any transformer will short-circuit the generator.

Fig. 10 shows the same system of connection but with the generator ground omitted. In this case a ground upon a primary or secondary line will short-circuit one transformer of the group and the two remaining ones will be operated at 73 per cent. above normal potential; also the strain between the ungrounded wires and the ground will be that due to the full line voltage.

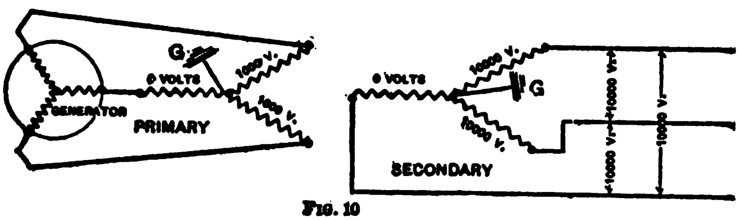


FIG. 10

Three-Phase Star. Primary and Secondary Neutrals grounded. Line Voltage 1000 to 10,000. Normal transformer voltages, 580 and 5800. Ground on one line wire short circuits one transformer, increases voltage on other transformers 73%, raises two line wires 10,000 volts above ground.

Thus for a star connected system the grounding of the neutral points is of no value in limiting the voltage strains on the system unless the neutral point of the generator be also grounded; in fact, the grounding of the transformers without the grounding of the generator increases the chance for trouble, since a ground upon any line wire increases by 73 per cent. the voltage of two of the transformers.

Star-to-Delta System.

Fig. 11 shows a star-to-delta system. With this method of connection no excess voltage can be obtained on any transformer, and not more than full voltage strain to ground, provided the delta remains closed; but with the delta open at one point and a

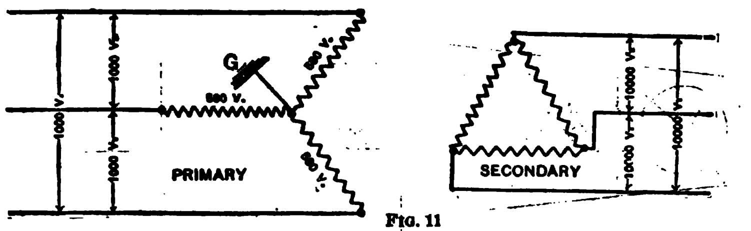


Fig. 11

Star to Delta System.
Line Voltages 1000 and 10000.
Transformer Voltages, 580 and 10000.

short-circuit on one transformer (Fig. 12), the voltage on the two remaining ones will be increased 73 per cent. and across two sides of the delta there will be *three times normal voltage.* Thus, on a 10000 volt circuit, 30000 volts may be obtained in case a transformer is short circuited and cut out of the delta.

This excess voltage across the two sides of the delta is due to the fact that a short-circuit on the star changes the angular position of the voltages from 120° to 60°, which in turn changes the angular position in the delta from 60° to 120°.

Delta-to-Star System.

With this system it is impossible to obtain voltages higher than normal upon any transformer or between any two line wires. A short-circuit in one transformer may, however, cut it out of the

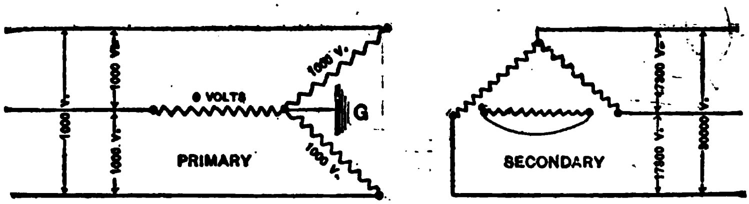


Fig. 12

Same as Fig. 11 except that Delta is opened and one transformer short circuited. Voltage of two transformers increased 73%. Voltage between two line wires increased 200%.

delta but leave the star-connection intact. In such a case the voltages will be as shown in Fig. 13. Two of the transformers operate at normal potential, with normal potential between two of the line wires, but with 58 per cent. of normal between the other wires.

STAR-TO-DELTA, RAISING. DELTA-TO-STAR, LOWERING.

In Fig. 14 is shown a transmission system with raising-transformers connected star-to-delta, and lowering-transformers connected delta-to-star. The voltages obtained across transformers and across line wires are shown. The neutral points of the low-tension windings of both raising and lowering-transformers are grounded, generator neutral not grounded.

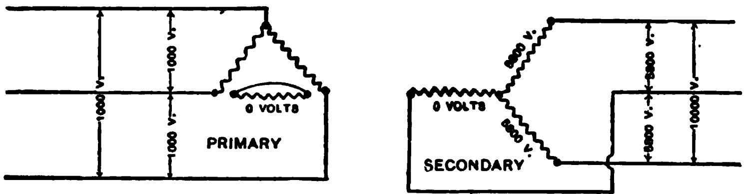


FIG. 13

Three-Phase Delta to Star System. Line voltages 1000 and 10000. Transformer voltage 1000 and 5800 One transformer short circuited and cut out of Delta. Two transformers continue to operate at normal voltage, giving 10000 volts across two line wires, 5800 volts across others.

Fig. 15 shows the voltages which will be obtained with a ground on one low-tension lead which short-circuits one transformer. The high-tension side of this transformer is cut out of the delta. The voltage across the other transformer is increased 73 per cent. and the phase relation changed from 120° to 60°, the voltages being as shown in Fig. 12. On the lowering-delta, three times normal voltage is impressed on one transformer and 73 per cent. above normal voltage on the other two. The voltages obtainable across the star on the lowering-transformers are readily understood from the figure. It will be noted that across one phase there is normal voltage and across the other two phases

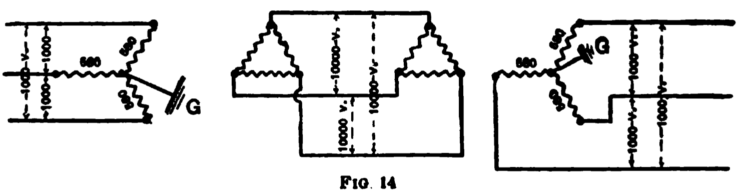


FIG. 14

Star to Delta Raising Delta to Star Lowering Neutral of Raising and Lowering Transformers grounded.
Line Voltages 1000 to 10000 to 1000. Transformer Voltage 580 to 1000 to 580.

2.7 times normal voltage. It is probable that a transformer subjected to three times normal voltage would take so large a leakage current as to blow fuses.

With this system of connections, grounding the neutral point of the star without a ground upon the neutral point of the generator is of no use in preventing unequal and excessive strains on the transformers and from line wires to ground. Should the

delta on the raising-transformers be kept closed, it is obvious that a short-circuit on any raising-transformer would short circuit the generator, but the above condition is one which might very possibly occur where switches or fuses are placed inside the delta.

DELTA-TO-STAR, RAISING. STAR-TO-DELTA, LOWERING.

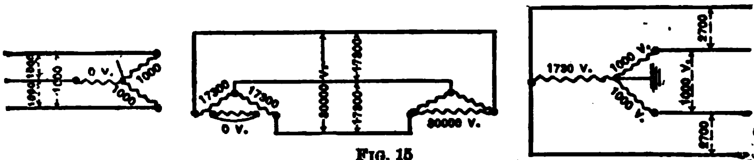


FIG. 15

Same as Fig. 14, except that one raising transformer is short-circuited and cut out of Delta.
Voltages on raising transformer 73% above normal and zero.
Voltages on lowering transformer 73% above normal and 200% above normal.
Voltages on high tension line 73% above normal and 200% above normal.
Voltages on secondary of lowering transformer normal and 170% above normal.

Fig. 16 shows voltages obtained under normal conditions with transformers connected delta-to-star and star-to-delta with low-tension and high-tension voltages of 1000 and 10000 respectively.

Fig. 17 shows approximately the voltages and phase angles obtained when one raising-transformer is short circuited and cut out of the delta, but with the star connection intact. The voltages obtained on the lowering-delta will be approximately those shown. It will be noted that this delta has been twisted far out of its normal form, though the voltage on no transformer has been raised above normal and on the lowering-transformer all voltages are below normal.

Fig. 18 shows the same connection but with one lowering-transformer short-circuited and cut out of the delta. The voltage across one of the remaining transformers is increased 73 per cent. while that across the other remains normal. The voltage across the open side of the secondary delta is increased 165 per cent.

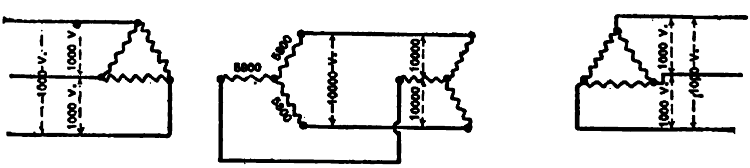


FIG. 16

Delta-to-Star Raising. Star-to-Delta, Lowering. Neutrals not grounded.
Line voltages 1000 to 10000 and 1000; transformer voltages 1000 and 5800 to 1000.

above normal; that on one transformer 73 per cent. above normal and on the other it is normal.

If the neutral points of raising and lowering transformers are grounded the abnormal conditions shown in Figs. 17 and 18 cannot be obtained, for in this case, with the lowering-delta closed

as in Fig. 17, the fuses will be blown when a lowering-transformer is short-circuited; and with the delta open as shown in Fig. 18, a short-circuit in the lowering-transformer will short circuit the generator.

Some abnormal conditions which may be obtained from a few of the possible combinations of transformers have been given

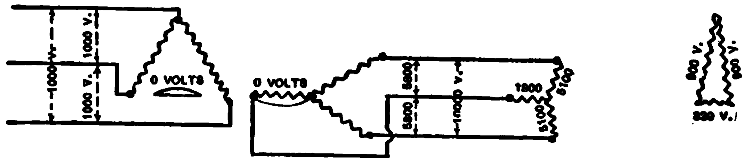


FIG. 17

Same as Fig. 16, except that raising Delta is open and one transformer short circuited. Voltage on lowering transformers less than normal. Note the extent to which the Delta is distorted. If neutral points of raising and lowering transformers be grounded, this distortion cannot occur, as fuses will blow when raising transformer is short circuited.

above. These abnormal conditions are produced by combinations which are accidental or unusual; but it is the accidental or unusual condition which must be taken into consideration and guarded against, if trouble is to be avoided. Some of the conditions which are shown, undoubtedly have occurred in practice and are possibly responsible for some of the troubles on high-voltage transmission systems.

It is obvious that a large number of combinations of raising and lowering-transformers in addition to those given above may be obtained, and in the following tables it has been endeavored to give the most common of these combinations and to show the abnormal conditions which are obtainable.

Resonance.—The abnormal voltages given above are those which are obtained from the generator pressure through direct

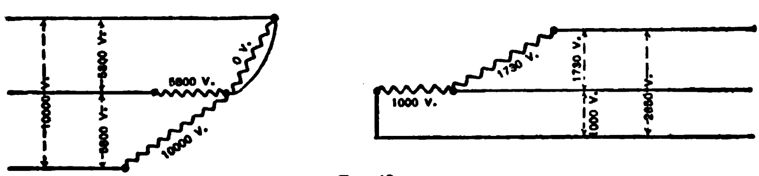


FIG. 18

Same as Fig. 16, except that lowering Delta is open and one transformer short circuited.
Voltages on raising transformers normal and 0.
Voltages on lowering transformers normal, 73% above normal and 0.
Voltages across secondaries normal, 73% above normal and 165% above normal.

transformation. Mr. Blackwell, in his paper, " Star or Delta Connection of Transformers," has called attention to another cause which may produce abnormal voltages, *i.e.*, Resonance. This is particularly liable to occur when a high inductance, such as the winding of an idle transformer is in series with a large capacity, such as that of a transimssion line.

In the tables below, where the combination is such as to give an idle transformer in series with an active transformer and a transmission circuit, it is indicated in the column headed "Resonance."

TABLE I.

SYSTEMS OF CONNECTING TRANSFORMERS WITH VOLTAGE STRAINS OBTAINABLE.

SINGLE TRANSFORMATION.

System.	Neutral.	Maximum Voltage. Per Trans. %	Between Wires. %	To Ground %	Possibility of Resonance.
Single-phase or 2-phase-4-wire	(a) Grounded.	100	100	50	No.
Single phase or 2-phase-4-wire	(b) No Ground.	100	100	100	No.
2-phase-3-wire	" "	100	140	140	Yes.
3-phase Delta..	" "	100	100	100	No.
3-phase V......	" "	100	100	100	Yes.
2-phase-3-phase or 3-phase T..	(a) Grounded.	100	100	58	"
2-phase-3-phase or 3-phase T..	(b) No Ground.	100	100	100	"
3-phase-Star...	Grd. or not Grd.	173	100	100	"
3-phase-Star...	Transformer and Generator Grd.	100	100	58	"
3-phase-Star to Delta.......	(a) Trans. and Gen. Grd. Delta Open or Close	100	100	100	No.
	(b) Grounded Delta Open.	173	300	300	Yes.
	" Closed.	100	100	100	No.
Delta to Star....	(a) Grd. Delta Open.	100	100	100	"
"	(b) Grd. Delta Closed.	100	100	100	"

TABLE II.

SYSTEMS OF CONNECTING TRANSFORMERS WITH VOLTAGE STRAINS OBTAINABLE.

DOUBLE TRANSFORMATION.

System.		Neutral.	Maximum Voltage.					Possibility of Resonance.
			Per Transformer.		Between Wires.			
Raising.	Lowering.		Raising.	Lowering	High Tension.	Low Tension.	To Grd.	
			%	%	%	%	%	
ΔΔ	ΔΔ	No Grd., Deltas open or closed................	100	100	100	100	100	No.
ΔΔ	Δ Y	" " " " "................	100	100	100	100	100	No.
"	YY	Grd. or no grd. Deltas, open or closed..........	100	173	100	100	100	"
"	Y Δ	(a) " " " " "	100	100	100	100	58	"
"	"	(b) " " " open....................	100	173	100	300	100	"
YY	YY	(a) Grd. on all transformers and generator......	100	100	100	100	58	Yes.
"	"	(b) No grd. on generator, transformer grd. or not	173	173	100	100	100	"
"	ΔΔ	(a) Grd. on generator and transformers, Delta open or closed.......................	100	100	100	100	58	"
"	"	(b) No grd. on generator, delta open or closed.	173	173	100	100	100	"
"	Δ Y	(a) Grd. on generator and transformers, Delta open or closed.........................	100	100	100	100	58	"
"	"	(b) No grd. on generator, delta open or closed.. Trans. grd..........................	173	100	100	100	100	"
"	Y Δ	(a) Grd. on generator and transformer, delta open or closed...........................	100	100	100	100	58	"
"	"	(b) No grd, on generator, grd. on raising. Delta open...........................	173	173	100	300	100	"

TABLE II.—Continued.

System.		Neutral.	Maximum Voltage.					Possibility of Resonance.
			Per Transformer.		Between Wires.		To Grd.	
Raising.	Lowering.		Raising.	Lowering	High Tension.	Low Tension.		
			%	%	%	%	%	
Δ Y	Δ Δ	(*a*) Gr. deltas open or closed	100	100	100	100	58	Yes.
"	"	(*b*) No grd. Deltas open or closed	100	100	100	100	100	"
"	YY	(*a*) Grd. on all transformers. Delta closed	100	100	100	100	58	No.
"	"	(*b*) Grd. on all transformers. Delta open	100	100	100	100	100	Yes.
"	"	(*c*) No. grd. Delta open	100	173	100	173	100	
"	Δ Y	(*a*) Grd. on transformers. Deltas closed	100	100	100	100	58	No.
"	"	(*b*) Grd. on transformers. Deltas open	100	100	100	100	100	Yes.
"	Y Δ	(*a*) Grd. on transformers. Deltas closed	100	100	100	100	58	No.
"	Y Δ	(*a*) Grd. on transformers. Deltas closed	100	100	100	100	58	No.
"	"	(*b*) No grd. on lowering on no grd. on raising lowering delta open	100	173	100	300	100	Yes.
"	"	(*c*) Grd. on raising and lowering, lowering delta open or closed	100	100	100	100	58	"

TABLE II.—Continued.

Y △	△△	(*a*) Grd. on generator and transformer, Deltas open or closed	100	100	100	100	100	No.
"	"	(*b*) No grd. on generator, raising Delta open, lowering delta open or closed	173	300	300	300	300	"
"	Y Y	(*a*) Grd. on generator and transformer, Delta open or closed	100	100	100	100	58	"
"	"	(*b*) No grd. on generator, grd. on transformers, Delta closed	100	173	100	100	100	"
"	"	(*c*) No grd. on generator, grd. on transformer, Delta open	173	173	300	300	173	"
"	△ Y	(*a*) Grd. on generator and transformer, Delta open or closed	100	100	100	100	100	"
Y △	△ Y	(*b*) No grd. on generator, transformer grd. or not Deltas closed	100	100	100	100	100	No.
"	"	(*c*) No grd. on generator, transformer grd. or not, raising Delta open	173	300	300	270	300	"
"	Y △	(*a*) Grd. on generator and transformer, Deltas open or closed	100	100	100	100	58	"
"	"	(*b*) No grd. on generator, lowering Delta open; grd. on transformers	100	173	100	300	100	"
"	"	(*c*) No grd. on generator, raising and lowering Deltas open; grd. on transformers	173	173	300	265	300	"

In the above tables, it has not been attempted to show all the operating conditions with each of the combinations. The remaining ones may, however, be readily worked out.

In addition to the combinations given above there are the 2-phase-3-phase, 3-phase-V and 3-phase-T connections which may be used at either the raising or the lowering ends. When used for raising transformers, these combinations will deliver their proper voltages to the line provided the proper voltages are impressed on their primary terminals, as it is impossible by short-circuiting one transformer to raise the voltage of the other.

When used as lowering-transformers these combinations will supply to the secondary circuits, voltages of proper amount and bearing the proper phase relation to each other, provided the voltages impressed on the primary side are of proper amount and proper phase relation to each other. If, however, the voltages applied to the primary are distorted then the voltages delivered by the secondaries will be correspondingly distorted.

Grounded Neutrals.—It will be noted that in many cases the grounding of the neutral points of a transmission system limits the voltage strain to ground and the voltage which may be obtained across any transformer, and in such cases grounding would seem advisable. This is notable in the case of the star-system with grounds on transformer and generator neutrals. There is, however, a danger arising from this grounding which should be carefully considered. In case of trouble on the circuits, current may flow through the ground to the neutral; in thus flowing it will naturally take the path of least resistance, so that if telephone or telegraph lines, which have normally low resistance to ground, parallel the transmission circuit, the current will flow along these wires, often with disastrous results to the circuits.

Two cases of trouble are particularly liable to give these conditions:

First:—Where the neutral points of the high-tension windings of raising and lowering-transformers are grounded, the opening of one or two of the three transmission wires will cause currents to flow through the ground.

Secondly:—A high resistance ground on a transmission wire will partially short circuit a transformer and cause current to flow through the ground to the neutral.

Some plants have been able to operate satisfactorily with grounded neutrals; with others this grounding has caused great disturbance on telephone circuits, and in one plant it is reported that the blowing of a fuse on one of the high-tension wires put out of service the telephone systems in " ten counties." Thus, while grounding of neutrals may be permissible in certain localities it may not be allowable in others; and in laying out a plant it would seem to be advisable so to arrange the apparatus that it may be safely operated without grounding the neutrals.

An examination of the tables given on the previous pages indicates that the delta-system is the one giving the minimum chance

of trouble. Under certain conditions, however, the star and star-delta systems will give satisfactory service.

The choice of a system of connections for any high-voltage transmission system is evidently a matter which should be carefully considered, account being taken of the possibility of obtaining excessive voltages under accidental conditions, the chance of trouble on parallel circuits, due to grounded neutrals, and the possibility of obtaining resonance when switching or under other similar conditions.

President Scott:—The question of grounding one point of a transmission line is a very important one, and it is one which has received a good deal of attention during the last few years. I remember when some engineers with whom I was acquainted went West to visit transmission plants, I asked them to look into that point particularly, and from the evidence which they got, and from the evidence that I obtained when I took a trip West some time ago, and from what I have heard since, I have concluded this—that some plants grounded the neutral, and its engineers considered it safe and would never think of running in any other way, while the engineers of plants which did not ground the neutral would never think of doing such a thing. It is an important question; it is partly theoretical, it is largely practical and one which is not yet settled. We should like particularly to hear from out western friends on this point. The subject is open for discussion.

Mr. Hayward:—As you say, Mr. President, this has been a subject of discussion for a good while, as to whether to ground or not to ground, and our friend Mr. Nunn has been operating his lines grounded from the very start, but I believe Mr. Gerry is operating without ground. We, with our 16,000 or 17,000 lines, have operated with a double delta connection without any grounds on. The experiences we have had without grounds are, of course, that you may have a short circuit on one wire, and the wire down, and you could still keep running. Still, I believe—and this is only an opinion—that when we get up to any very high voltage, after all it is better to ground the neutrals and keep them grounded everywhere. It is better, I think, to avoid any chance of these extra high voltages that may occur, and I want to say very emphatically that they have occurred in practice, where some of the conditions mentioned by Mr. Peck and some mentioned by Mr. Blackwell have held. I therefore think that it is probably best to ground every neutral point. We are changing from a delta-delta connection to what will be a Y to delta connection and various other connections which we have not been running hitherto, simply because we are changing our voltage on the high tension lines from 16,000 to 28,000, and we intend to change our distribution in Salt Lake City from 2,300 volt to Y-connected 3,800 volt. Of course, we all recognize the difficulty of a single short circuit on a line with grounded neutral—or single breakdown on the line with grounded neutral—

means short circuit. Yet, after all, we have to recognize this, that our lines must be made so that they will not break down. There is just one point—the rise of potential mentioned in Mr. Blackwell's paper, page 151—the conditions holding in Fig. 3 or 4, I don't know exactly which, actually occurred in testing a transmission line in 1897. The conditions were that we had 37 miles of line. We connected the two circuits on the pole line together solidly, making a line out and back of 74 miles. We got a delta-star connection and tried to see what the charging current on the line was. Having tried with the three switches closed, we then thought we would like to see what it would be with only two switches closed; and as soon as we got up to about 25,000 or 26,000 volts an arc jumped across the wires, 12 inches apart. Not only did it do it once, but it did it every time. That is the condition mentioned by Mr. Blackwell right here. If you get the conditions that are laid down here they will occur sooner or later in practice, and they will find out your weak spot.

PRESIDENT SCOTT:—Mr. Gerry, we turn now naturally to you.

MR. GERRY:—I do not know, Mr. President, whether I can add anything of value to this discussion. The selection of either the star or the delta system of connecting transformers is, to a certain extent, a matter of engineering detail. I say this for the reason that I believe satisfactory results can be obtained by the use of a star connection, although not quite as good results as by the use of a delta connection, on a transmission line. The points of advantage and disadvantage have been referred to generally by Mr. Blackwell and Mr. Peck. The points brought out by Mr. Peck are of great interest, but a plant can be arranged in such a manner as to avoid practically all the dangerous conditions outlined for a plain star system. It is possible to provide. switching devices of such a nature that all three transformers will be cut out automatically, at the same time, in case of trouble with any one; or if a ground appear on the system, and this should always be done on a star connected transmission line, even if the neutral be grounded at the generators in addition to grounding at the transformers.

Mr. Peck, in introducing his discussion, says: " By the grounding of the neutral point of a transmission system, it is sought, first, to limit the strain from line wires to ground." Only a short time ago that was considered of great importance as reducing the strains on the insulation of the line. As a matter of fact, that does not limit the possible strain on the insulators to the pressure from wire to neutral. Even with all the neutrals grounded at the ends of the transmission lines, it is possible, owing to the resistance of the ground circuit, to have on the insulators the full line pressure between wires. In other words, even with a grounded neutral at the generators, it is possible locally, at points on the transmission line, to have the same pressure between the ground and any one line, that you have between any two wires of the circuit. Mr. Blackwell, in referring

to the advantages of a grounded neutral, in several instances states that in case of trouble, such as a ground on one of the wires, the result will be immediately to open the automatic devices and cut off the transformer coils from the line. Now, the same result can be accomplished with a delta connected system, by means of suitable automatic devices and without throwing a short circuit on the system.

There are a number of operating advantages of the delta connection, one of which I will mention. A transformer may be cut in and out of service, in and out of delta, with very great convenience and with no disturbance of the system, and considerable operating advantage is thereby obtained, especially where the number of transformers is limited. It has just been suggested that one advantage of the star system is that it is possible to put in transformers connected in delta, and afterwards increase the voltage by changing over to a star connection. As a rule, however, I believe it would be better to arrange the switches for delta connection, and accomplish the desired result by double winding the transformers, operating the coils at first in parallel, and later in series.

Mr. Converse:—Mr. Hayward referred to the plant of the Telluride Power Company. I have had considerable to do with the transformers of that plant. It is an old plant, at least we consider it so now. I would say that those transformers were built for star connection on a high-voltage and a low-voltage, and we have had some results there. A great many things have happened there, and I would ask Mr. P. N. Nunn, Chief Engineer of the Telluride Power Company, who is here, to tell us something of them.

President Scott:—I had it in my mind to call on Mr. Nunn very shortly. Mr. Nunn's work has figured largely in our Institute, both in papers which have been presented and in discussions from time to time; but Mr. Nunn himself, who has been so intimately connected with a great deal of this high-voltage and pioneer work, has not been very much in evidence. We are very fortunate in having him here.

Mr. P. N. Nunn:—In our Utah system, star connected transformers with grounded centers have been the rule, although the initial transmission employed three-phase two-phase step-down transformers.

Transmission difficulties have been chiefly traceable either to outside interference with our lines, or to the opening of circuits, especially by fuses. The line system is rather complex. the main transmission consisting of duplicate three-phase, three-wire, 40,000 volt lines extending from the Provo to the Logan power house, a distance of approximately two hundred miles, through the several markets of Salt Lake Valley. These are divided into sections, and so arranged that a defective section will cut out without interrupting the whole system. Until recently we have been obliged to protect these sections, as well

break?

as our generating and substations, with fuses and to switch at the same points with air-brake switches. Neither of these devices has been satisfactory. The blowing of a single fuse is often followed by the blowing of others, sometimes at distant points, and the opening or closing of switches sometimes produces the same result. It seems imperative that all wires of a circuit should be opened or closed simultaneously, and in this respect the automatic triple-pole oil-switches, with time-limit attachment, which are now being installed, should prove invaluable.

The mere opening or closing of circuits may have caused excessive rise of voltage, as we certainly have had at times some abnormal rises. I recall clearly one instance when current jumped a full eight feet from a conductor to the steel framework of the roof of the station. This may have been due to atmospheric disturbances, although there were no indications of lightning.

From the first we found that a ground on one line did not short-circuit the generator, and noticed that the first indication of such a ground was the arcing of the current over the lightning arresters. Investigation of the conditions led to the discovery that we had full line voltage between the remaining lines and ground, which accounted for the disturbance on the arresters, and also full line voltage on the active transformers, instead of the normal 58 per cent. of line voltage. No transformers have ever been burned out due to this condition, and no serious inconvenience has been suffered so far as I know.

This plant has been in operation nearly six years, employing as stated, star-connected, grounded center transformers and on the whole has been, I think, a pronounced success. Whether the difficulties mentioned have been aggravated by the connections of the transformers, or whether we would have suffered less with delta-connected transformers, I do not know.

PRESIDENT SCOTT:—I would like to ask Mr. Nunn about one point. You have grounded the central point of the high-tension system. Is the central point of the generator grounded primarily?

MR. NUNN:—The central points of both low and high-tension winding of the step-up transformers are grounded. The generator winding is not otherwise grounded.

MR. THOMAS:—Mr. Blackwell's paper contains a statement on page 151 which I think needs a little further explanation—the last paragraph:

" It is theoretically possible for a potential 100 times that for which a transformer is wound, to be caused by opening the primary switches, etc."

Of course this is true if we neglect all true energy losses in the system, but there is inherently linked with the condition which he speaks of here an energy loss which must necessarily limit this rise of potential very materially. That will probably bear a little further analysis.

The conditions of resonance at normal generator frequencies, as shown in most all these discussions, requires that the leading current to a transformer line pass through a transformer in one winding, the other winding being open circuit The only way it is possible to get a high enough inductance to meet the condition for resonance is by means of iron in the magnetic circuit in the transformer. As we all know, there is a considerable true loss represented by the energy taken by an open circuited transformer—open circuited, I mean, in the other winding. In some designs I have looked over, this true loss is almost as great as the apparent loss, though not quite so great. In other designs the true loss, I presume, may be half as great as the apparent loss. Now, the resonance results from the action of the potential from some generating source, which builds up oscillations in the oscillating circuit. This generator must supply the true loss. If the true loss is nearly half the total apparent energy, taken by the transformer when connected across the mains,—I mean the total energy, now, considering impedance—then if we should by resonance increase to double this true loss by increasing the voltage on the transformer, no higher potential can be built up, because all the true energy supplied by the generator is absorbed. This can be made a little clearer by considering the formula which gives the result of the current in the circuit containing inductance, capacity and resistance when conditions are right for resonance.

$$\text{Resonance Current} = \frac{\text{General Voltage}}{\sqrt{R^2 + \left(p^L - \frac{1}{pc}\right)^2}} \times \text{Sin}\left(p\,t - \tan^1 \frac{p^L - \frac{1}{p\,c}}{R}\right)$$

This formula states that the current equals the potential applied from the generator, divided by the true impedence of the circuit, which can never be less than the ohmic resistance R. If this allows only double current on normal voltage, resonance can cause no greater rise. Since the ratio between the true loss and the apparent loss of transformers changes materially with changing induction in the iron, and when above saturation the magnetizing current goes up very fast in proportion to the true energy current turns, it follows that perhaps the resonant current may have to increase several times to cause a doubling of the true loss. This suggests another point if you have the proper frequency for resonance, before e.m.f. is applied, assuming normal magnetic induction in the iron of the transformer. Then if resonance builds up the voltage to perhaps three or four times normal potential, the induction of the transformer has also changed very materially on account of the greater magnetizing

current causing a great lessening of permeability and a reductioı of the inductance as a choke-coil. Consequently the natura frequency, of the generator, which should give resonance wil. perhaps be several times larger than before the rise of potential started. It is thus quite unlikely with this type of choke-coil that resonance would reach a very high value, even if it were not limited by the true loss. However, when the inductance through which the resonance occurred is not denied for a closed magnetic circuit, as in the case discussed, the true loss is a very small percentage of the total apparent energy and no low limit to the resonance rise can be thus assumed.

In regard to static resonance—I mean resonance at very high frequencies, where choke-coils without rim coils might have the proper resonance values—it seems to me there is little danger of a very considerable rise, because, so far as I know, there is no source of continuous, constant value alternating e.m.f. at a very high frequency. Most discharges we get are perhaps oscillatory, but they lose their intensity very rapidly, two or three oscillations, only, probably, having anywhere near the maximum values of potential.

I would like to ask Mr. Mershon, in the absence of Mr. Blackwell, whether Figs. 5 and 6 on page 152 should not show a ground on either line *A* or *C*, or some form of unbalancing. As those stand, I do not believe that resonance can occur. For instance, in Fig. 5, we have the natural tendency when the generator excites the lines for changing current to pass from *B* to *A* and from *B* to *C*, but these currents will be equal if there is no unbalancing, and since they pass in opposite directions, through the halves of that idle transformer, there would be no choking effect except the small amount due to the magnetic leakage of the transformer. In Fig. 6, the natural tendency is, for the charging current to pass from *A* to *C*, and even if the line *B* is connected at the middle point of the transformer, it is naturally at earth's potential and would never receive any charging current at all. Of course, if either line is then balanced or grounded there then appears a condition for resonance. Am I right in this conclusion?

Mr. Lincoln:—Just one point; I was going to mention a number, but Mr. Thomas has got in ahead of me on the others. One point struck me in connection with the statement of Mr. Blackwell, that theoretically 100 times normal potential was possible in a condition of this kind—resonance. In that connection I was very much interested in reading a contribution by Mr. M. I. Pupin, contributed to the Transactions of this Institute in 1893, in which he showed how very difficult it was to maintain resonance with iron circuits. He showed that resonance, where there was no iron in the inductance, was very marked, but as soon as iron was introduced into his coils the difficulty of obtaining resonance conditions became extremely marked and very difficult to obtain; and that same condition

would, I think, apply here, where you have iron in the circuit of the choke-coil, and would prevent a rise in voltage anywhere near approaching that stated by Mr. Blackwell.

MR. PETER JUNKERSFELD:—In Chicago we have been operating a 4-wire-3-phase-60-cycle overhead system with a grounded neutral for about three years. The generators are star connected, and the common point is connected to the ground. It has been very successful from the start. We, however, ground in the station only, and do not ground any other point of the primary system. The neutral, on the secondary of transformers, is also grounded.

In our underground system, which is operated at 9,000 volts and 25 cycles, we likewise operate now with the grounded neutral. For the first four or five years' development while the voltage was only 4,500, we had step-up transformers and they were connected in delta, but the next step beyond that was to double the voltage to 9,000 and install line voltage generators, which have been operated with the grounded neutral. There is one thing though that we have discovered, or rather which has been brought to our attention very forcibly. That is, the necessity of doing away with single-pole switches and fuses, and things of that sort. We have nothing but straight 3-pole oil-switches. We have no plug change-overs, or fuses or single-pole switches. Those have all been done away with, and we believe it is very necessary to do so.

I might say that a great many of the conditions that are laid down here by Mr. Peck and Mr. Blackwell, as Mr. Hayward very forcibly brought out, do occasionally occur in practice, and that is something which needs a great deal of attention. As regards the delta or star-connection, in our experience we have found that the number of transformer troubles are after all comparatively few. In six years I can recall only four, possibly five, cases of serious transformer trouble in substations. With the increase in the number of transformer and rotary converter units feeding an interconnected network, we have come to the conclusion that the advantage of having delta-connected transformers in order to be able to cut out one of the bank and operate with two, is not very great. In the earlier history, when our installations were small and few in number, it was an advantage to have the delta-connected outfit, but with a larger number that advantage disappears, and to-day we are installing Y-connected 3-phase transformers, the idea being that these transformer accidents occur very rarely, and when they do occur a whole unit is usually shut down, in any event for a short time, and we can then just as well afford to have it shut down until such time when the whole 3-phase outfit can be replaced.

MR. MERSHON:—Mr. Gerry said something in regard to automatic means for cutting banks of transformers free on both sides. That would mean reverse circuit-breakers, and it would mean not only reverse circuit-breakers, but it would mean 40,000 our

50,000-volt circuit-breakers. Mr. Gerry knows something about automatic circuit-breakers for 40,000 and 50,000 volts. I would like to hear from him in regard to that.

Mr. Gerry:—My remarks just now were intended to indicate that with proper arrangements, either the star or delta connection might be used with good results. If star connections are used on high voltage transformers, in fact on any transformers, it is desirable, in order to obtain proper safety, to have devices which will open all three legs of the circuit at one time but if the delta-connection be employed, you may use single-pole switches. For this and other reasons, up to the present time, I have always considered that there were advantages in using a delta-connected system. Single transformers may be conveniently switched into and out of service; single-pole switches may be employed if desired and at the same time all those excessive potentials mentioned by Mr. Peck will be avoided and resonance will not be likely to result. In other words, a plain delta is at once a flexible and safe arrangement to adopt.

In reference to high-tension circuit-breakers for transmission lines, the time is coming, if it be not here already, when an oil-switch can be obtained, together with reverse current and overload operating devices for any voltage and capacity, which will open all three legs of a circuit. Mr. Nunn touched upon this subject just now, and it is of great importance, especially with a star-connected system. Whether the star connection is the more desirable is another question, but I do not consider it vital in connection with operation, if proper precautions are taken. I do, however, consider the proper arrangement of switches, with either the star or the delta, a very important problem in connection with the system.

Mr. A. L. Mudge:—Page 149, lines 16 and 17, the words "And the other two still deliver 3-phase power up to their full capacity, *i.e.*, two-thirds of their bank," should read, I think, as follows: "And the other two still deliver 3-phase power up to 86.6% of their full capacity, *i.e.*, 57.7% of their entire bank."

Mr. J. E. Woodbridge:—The special case of high-tension distribution of power for the operation of rotary converters brings up some considerations not mentioned in Mr. Blackwell's Introduction.

In distribution of this kind the secondary voltage of the step-down transformers is so low that there is no advantage in a Y-connection of the secondary coils. In fact, this would prove a positive disadvantage. For this reason a delta connection of the secondary windings is to be preferred for 3-phase converters. With the primary windings connected Y and the secondaries delta, operating synchronous machinery, there is no instability of the neutral. While it is true that a Y-delta connection of three transformers with no neutral lead throws the whole bank out of service if one is disabled, the grounding of the high-tension neutral of both the step-up and step-down banks

gives a radically different condition. With this connection one transformer of the three may be taken out of service and the remaining two will continue to deliver 3-phase current just as will two transformers connected delta-delta on a 3-phase system. It will be noted that when one transformer on a Y-delta connection with grounded neutral is taken out of service, one of the three line wires is also open-circuited. Thus not only does this connection allow service to be resumed with one transformer crippled, as soon as this transformer can be disconnected, but it allows service to be continued with one line wire in trouble, either broken, crossed with another wire, grounded or attached to a punctured insulator. It has often been claimed for the delta-delta connection of transformers that the ability to operate on two in case of trouble with the third is a great advantage. There are now in operation in this country many railway distribution systems with lines of moderately high-tension, 10,000 to 15,000 volts, put up on trolley-supporting poles along the right of way, which frequently is the public highway, with many trees and many turns, and lacking the substantial and carefully worked out details of the lines of heavy transmissions. These railway distribution plants, so built, are subject to unavoidable line troubles many times more numerous than transformer breakdowns. It seems to the writer that any connection of the transformers which allows operation with one line wire in trouble is much more valuable in such cases than any which simply provides for transformer troubles.

The drop on a 3-phase line with grounded neutral is increased just 50 per cent. when one line wire is thrown out of service, the other two being used on Y-delta connected transformers; this being based on the assumption that the ground or track return has a negligible resistance in the high-tension transmission. The writer has operated a railway substation in this way on two wires, starting a rotary converter as an induction motor by means of alternating currents applied directly to its armature, and carrying the load with two wires in service with no apparent difference in the operation from the usual results obtained with all three wires in service. In fact, much to the writer's surprise, there was no apparent effect on the telephone line which was on the same poles with the high-tension line for several thousand feet, one of the three high-tension wires being completely disconnected at both ends. At one time while operating in this way the transmission line became reduced to one active wire and ground, owing to the melting out of a temporary low-tension connection. The substation continued to carry its load and the trouble was not noticed for some time.

It is also of interest to note in this connection that 6-phase rotary converters supplied from diametrically connected transformers will start and carry load satisfactorily when supplied with power on two diameters only. With a Y diametrical connection of the step-down transformers and with a grounded

neutral the cutting out of one transformer would of course reduce the supply of the 6-phase converter to two diameters. It is almost needless to state that a 6-phase converter with double-delta low-tension connection would operate satisfactorily on two transformers.

Referring somewhat more in detail to the advantages and disadvantages of a grounded neutral, an investigation of the action in case of a punctured or broken line insulator is of interest, as most of the serious line troubles come from insulator breakdowns causing the burning off of cross-arms or pole tops which frequently results in complete shutdown. With no ground on the neutral, the puncturing of an insulator generally manifests itself as a ground on the system. To guard against burning of cross-arms or poles, it is possible to solidly ground the faulty phase, thus removing all electromotive force from the faulty insulator, but this method seems open to the objection that if one insulator will break down under the Y voltage of the system, it is inadvisable to subject two-thirds of the total number to nearly twice this voltage. Some lines are now being built with a fourth wire with switching arrangements at each end of same, so that in case of trouble on one wire the fourth can be connected into circuit in place of the faulty conductor. With a grounded neutral the question arises whether a broken insulator would cause sufficient leakage to open the circuit through overload, or would burn off cross-arm or pole-top without giving previous notice to the station attendants. A ground wire on the poles electrically connected to an iron pin in each insulator would make a short circuit of each insulator breakdown, and would prevent burning off of pole tops. With instantaneously acting autometic switches it would also prevent what is sometimes worse, *i.e.*, the burning apart of transmission wires and dropping of same across other circuits or to the ground.

Another factor that is affected by the grounding of the neutral is the protection against lightning. On a line with no ground of the neutral it is essential to have enough gaps to prevent a discharge under the full rated voltage between wires. This voltage is applied when one corner of the circuit becomes grounded. It is also necessary to provide enough resistance in each branch of the discharge path to prevent an arc holding when a discharge occurs under this voltage. With grounded neutral the maximum voltage between any one wire and ground is reduced nearly 50 per cent., allowing material reduction of the number of gaps and resistance in the discharge paths.

From the above consideration the writer believes that extra high voltage systems, that is, those with working pressure between wires of over 25,000 or 30,000 volts, should have the high-tension windings of their step-up and step-down transformers Y-connected with the neutrals grounded.

(Communicated after Adjournment by Dr. Louis Bell.)

Note on Mr. Blackwell's Paper.

It should be noted that the Y systems, which are immensely

valuable in saving copper, also entail some additional care, as is the case with all copper-saving connections. In practice I have found that mixed delta and Y connections are desirable and tend to steady the regulation. I believe in the grounded neutral as a safety measure, but sources of accidental grounds should be followed up rigorously and carefully eliminated. In using Fig. 1, this is especially necessary, and it is a good thing to ground through light fuses or lightly set circuit-breakers, but one usually has to ground this system since its main use is in making long runs where high voltage lines are barred, and the Fig. 1 connection carries one below the prohibitive restrictions placed arbitrarily to allow old arc machines to run while blocking modern distributions.

A paper presented at the 20th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., July 1, 1903.

ELECTRIC CABLES FOR HIGH VOLTAGE SERVICE.

BY HENRY W. FISHER.

In the early part of the last decade there was a general belief among electrical engineers that rubber-covered cables would be used almost exclusively for high-voltage service and paper-insulated cables for comparatively low voltages. With the improved manufacture of the latter, opinions have changed so that some engineers prefer paper to rubber, stating that in their experience the life of paper cables is longer than that of rubber cables. To account for this they believe that the strain caused by very high voltages gradually deteriorates the rubber by some kind of electrolytic action, or by a purely physical action, or by a tendency for static discharges gradually to penetrate farther and farther until a breakdown occurs. In substantiation of their claims they give instances where rubber cables have broken down one after another in service without any apparent cause. On the other hand, there are engineers who claim that they have operated rubber cables at high voltages continuously without any trouble. The ability of a rubber-insulated cable to withstand high voltages depends upon the ingredients entering into the composition of the rubber compound. The dielectric strength to resist electric pressure becomes greater within certain limits with increased percentages of pure Para or other high-grade rubber; and there is good reason for believing that when lead-covered cables are employed, the life of rubber-insulated cables is lengthened with increased percentages of such rubber. This subject should naturally be treated under three headings

First: Manufacture of cables.
Second: Installation of cables.
Third: Operation of cables.

First: *Manufacture of Cables* —In the manufacture of paper-insulated cables for high voltages, great care has to be exercised in selecting the right kind and quality of material, and also in the methods of construction and impregnation of the paper with insulating compound. The most experienced engineers now realize that cables saturated with oily compound can better be handled without injury to the dielectric, and also resist better high voltages. The use of oily compound is, however, accompanied with lower insulation resistances, and consequently many engineers who think they are adopting the best practice by specifying several hundred megohms per mile, are in reality inviting bids on an undesirable type of cable. The best cables either with paper or rubber insulation should be able to resist comparatively high voltages for an extremely short period of time. Such voltages are obtained at the time of making or breaking the circuit, or during short-circuits. To illustrate: If a cable of inferior material and construction be subjected to a gradually increasing voltage till a breakdown occurs, and then after removing the burnt-out part the operation be repeated, a second breakdown will almost invariably occur at much lower voltage than at first, showing that the cable was injured by an impulsive rise of voltage at the time of the first burn-out. With the best cables the difference between successive voltages applied as above is much less than is the case with inferior cables, and at the same time the former withstand very much greater voltages for the same thickness of insulation. If the question of expense is not a consideration, paper insulated cable can be made of remarkable dielectric strength. On one occasion the writer designed such a cable with a thickness of insulation capable of ordinarily withstanding 16,000 volts. Extraordinary care was exercised in the manufacture of this cable, and when tested 48,000 volts were required to break it down, and during successive tests the voltages applied scarcely varied 1,000 volts from the above figure, showing a very great uniformity. Such a cable would have a greater dielectric strength than that of ordinary rubber cables, and at least equal to that of rubber cables with high percentages of Para, and would cost fully as much as the latter.

In the manufacture of rubber cables, care has to be used in

selecting the best and proper materials; and the work of mixing them and masticating and appyling the rubber must be done uniformly well, and the process of vulcanization must be carried on at the right temperature and for the right length of time to suit the particular compounds. After being made, all high voltage cables should be subjected to the usual test for insulation resistance and electrostatic capacity, and also to voltage tests of double the normal working e.m.f. Even if this test is not specified the manufacturer should apply it for his own protection.

Second: *Installation of Cables.*—This work must be done by well-trained men, as a small amount of carelessness may mean much trouble and expense. When the cables are pulled into ducts great care must be exercised to prevent abrasion of the lead cover, and no sharp bends must be made because in so doing the insulation may become injured or cracked. It is advisable not to pull paper insulated cables into ducts during extremely cold weather, because of the possibility of cracking the insulation. If such work of installation has to be done, the reels of cable should be kept in a warm place over night, or else put under a tent for a few hours and kept warm with plumber's furnaces placed so as not to overheat the cable at any point.

The work of jointing the cables must be done by good jointers who are in turn carefully watched by an experienced foreman. Different companies make different forms of joints, but after a reliable one is adopted the work should be systematic and according to definite directions in all particulars. By so doing, remarkable records of perfect workmanship have been made. After complete installation each cable should be subjected to double the working voltage, but this voltage should not be applied or broken suddenly because by so doing unnecessary strains would be imposed upon the cable.

Third: *Operation of High Voltage Cables.*—This is a subject that could better be presented by the operator of the electric light and power plants where cables are employed. However, as one of the objects of this short paper is to invite discussion, it may be well to state that a perfect protective device for cables and auxiliary apparatus would lessen to a very large extent the troubles of the operator incident to impulsive rises of voltage from switching and short-circuit. On several occasions and in different power houses, discharges have been seen to take place over the surface of switchboards at the time of short-circuits in cables, transformers, switches, etc. On some of these occasions

the rise in voltage necessary to make said discharges was estimated to be about four times the normal working voltage. At such times the original cause of the trouble cannot always be ascertained because frequently cables are burned out in several places, and transformers and apparatus injured at the same time. This kind of phenomena seems to be more prevalent and dangerous where air-lines connect with cables. It will therefore be seen that an efficient device which would protect cables and accessory apparatus from such excessive rises of voltage would be of incredible value to operators.

The question of the carrying capacity of cables is often not considered as carefully as it should be. With a great many cables all carrying normal currents are in one duct-system, the middle and top ones are apt to become very warm. The difference between the temperature of the conductor and that of the duct may be nearly as great as the difference between the temperature of the duct and that of the surrounding air, although generally speaking the former is the least. The carrying capacity of cables as frequently recommended is entirely too great when many cables are in the same duct-system.

There is a very great differenec in the radiating power of dry and wet-ducts, and in the heat conductivity of different soils, and so it is impossible to give set rules governing all cases. Under no circumstances should the temperature of the conductor be allowed to reach 90° Centigrade; and if twice the maximum difference of temperature between any duct and earth added to the temeprature of the earth is nearly equal to 90° there is reason for apprehension.

The above remarks do not apply to rubber covered cables, which should never be heated to over 65° or 70° C.

Moreover it is not desirable nor economical to heat paper insulated cables to 90° C., and the only reason for mentioning this figure is because such cables can withstand this temperature for a considerable length of time without deterioration.

A paper presented at the 20th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., July 1, 1903.

THE OPERATION AND MAINTENANCE OF HIGH-TENSION UNDERGROUND SYSTEMS.

BY PHILIP TORCHIO.

The following notes apply mainly to moderately high-tension systems as installed in large cities in the last few years.

(1) INDEPENDENT VS. PARALLEL OPERATION OF FEEDERS AT SUBSTATIONS.

By proper selection of size of feeders and transforming units at substations, each feeder can be operated to supply normally an independent group of transforming apparatus. In case of emergency the same apparatus can be arranged to be fed from other feeders through an emergency bus. This arrangement of independent operation of feeders has in most cases the disadvantage of not allowing the full use of the copper investment at light loads, but it has the following advantages.

(*a*) The short-circuit current fed back from the substation bus bars into a faulty feeder is limited by the reactance of at least two sets of transforming apparatus. This will materially help the final clearing of the short-circuit.

(*b*) In rotary converter substations the independent groups of transforming apparatus can be fed from different bus bars or from different generating stations, thereby increasing the reliability of service.

(2) TESTING OF CABLES.

(*a*) Periodic insulation tests are valuable as they furnish indications of abnormal conditions and often lead to the detection of faults on the systems. The instruments usually used in connection with insulation tests are a D'Arsonval galvanometer with

shunt, and a battery of from 70 to 100 volts. Periodic tests should be made at least once a week on each feeder, and oftener under abnormal conditions.

(*b*) High-voltage tests of dielectric strength of insulation should be carefully applied or possibly avoided entirely. Experience has demonstrated that failure of cable feeders are almost uniformly due to defective joints or mechanical injury to the cable. The record of all high-tension cable faults of a New York company for a period of five years is as follows:

Location of Faults on High-Tension Cables.

Made manifest by opening of circuit-breakers during operation.	Made manifest by low insulation test.	Reported by Line Inspectors.
1 in splice.	1 in splice.	1 injured in manhole by arc cable burnout.
1 nail driven into cable (external mech. injury.)	1 in splice.	
1 in sharp bend in manhole.	1 in splice.	1 damaged in manhole by A. C. lighting cables burnout.
1 in damaged sleeve (external mech. injury—cause unknown.)	1 leak of steam to cable end.	
1 in bend in small manhole.		1 damaged by outside parties doing subway work.
1 wet end of cable (external injury due to water leak.)		1 damaged as above.
1 wet end cups caused by steam (external mechanical injury.)		1 damaged as above.
1 steam in substation (external mech. injury.)		
1 in splice.		
9	4	5

Note that of the nine faults made manifest during operation, five were due to extraneous mechanical causes and four to defective installation.

The operating voltage of this system is 6,600 volts.

The lengths of high-tension cables in operation on December 31st of the first and last year covered by the record were 3.2 and 84.6 miles, respectively. The cables of this company have not been subjected to high-pressure test in subways.

This table shows that only four cable breakdowns out of 18 faults on high-tension cables could possibly have been prevented by having applied high-pressure tests to the cables originally. It cannot be determined how successful such tests would have been in other respects, as the testing strains might possibly have lowered the dielectric strength of the insulation at points otherwise perfectly safe for operating at the normal pressure. Note must also be taken of the fact that no failure of the cable proper has yet been recorded in this large system, now operating over 85 miles of high tension cables.

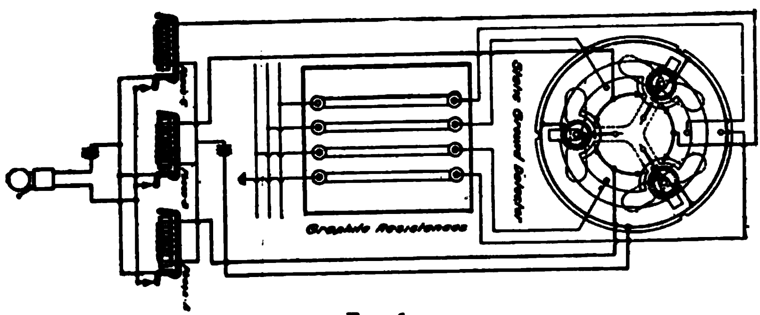


FIG. 1.

(3) INDICATORS AND PROTECTING DEVICES.

(*a*) Ground detectors with annunciator relay and drop-signal are desirable features of a high-tension switchboard equipment. The diagram (Fig. 1) shows an arrangement for a three-phase installation.

(*b*) Grounding of the neutral of high-tension generators is advocated by many engineers, and apparently it has given satisfaction wherever it has been tried. The objection to the heavy short-circuit current from one leg to ground has been overcome by the suggestion of grounding through a non-inductive resistance, thereby limiting the short-circuit current to a pre-determined amount. The experience of the companies so operating will be of great value.

(*c*) SPARK ARRESTERS.—It seems impossible always to guard against the appearance of high voltages due to sudden change

of load, grounds, short circuits, etc., and, especially in the latter case, spark-arresters will greatly increase the safety. These devices are preferably connected "delta" on system without grounded neutral and installed at the generator end as well as substation end of every cable and at every other place where the cable is looped into a substation or joins an overhead line.

(4) Apparatus and Methods for Care of Cables.

A new cable should not be connected to the main bus bars without being previously tested with full working pressure. This is sometimes accomplished through a suitable transformer properly fused or by inverting a rotary converter with a fuse on the low tension side.

A defective feeder often requires the application of high-voltage for breaking down the defective insulation and creating a low-resistance path for sending through it a direct current for the purpose of locating the fault by the compass method applied to the cable in successive manholes. To break down and charge the insulation requires about two amperes for paper and five amperes for rubber-insulated cables, applied for about five minutes. The regulation of the amperage could very conveniently be obtained by the use of a reactive coil, or what amounts to the same, a transformer of sufficient internal reactance to limit the current on short-circuit. But while there may not be much danger of resonance phenomena when using reactive coils, still there is some danger and it is, therefore, safer to limit the short-circuit current by resistance. Fig. 2 shows the connections of a rheostat intended to limit the short-circuit current to 2½ and 5 amperes at 6,600 volts.

(5) Rules.

In a large system it is important to devise a set of rules for the guidance of the men in the different departments. These rules must be rigidly complied with so as positively to eliminate any danger to men making tests or repairs to cables or switchbards.

(6) Maintenance.

It is not feasible to estimate accurately the life of high-tension cables and what will be the cost of maintenance after several years' installation. The cost of repairs for the first years is merely nominal, and the only other items of maintenance are the expenses for the periodic inspection and testing and minor details.

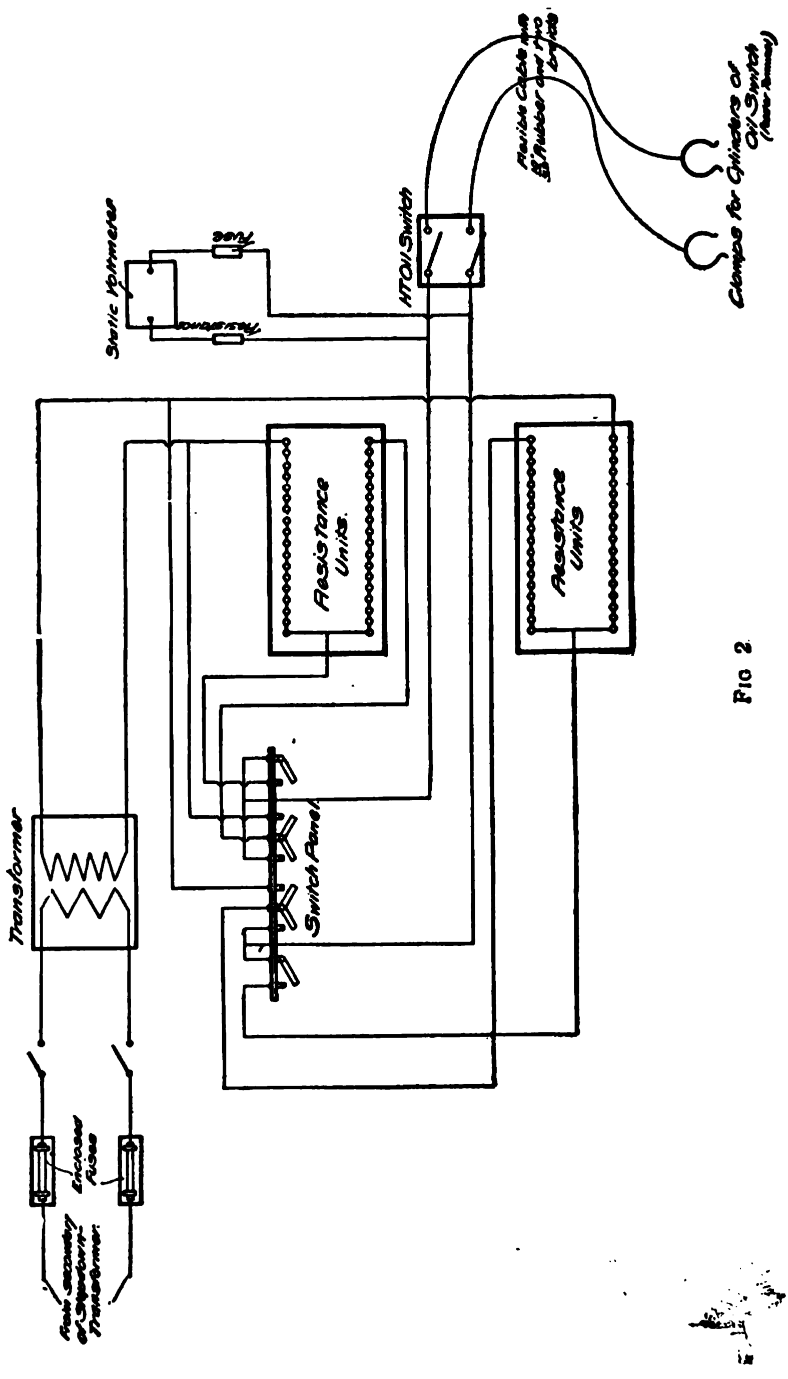

Transformer
Switch Panel
Resistance Units.
Resistance Units
Static Voltmeter
Fuse
Resistance
HT Oil Switch
Enclosed Fuses
Clamps for Cylinders of Oil Switch

FIG 2

A paper presented at the 20th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., July 1, 1903.

THE USE OF AUTOMATIC MEANS FOR DISCONNECTING DISABLED APPARATUS.

BY H. G. STOTT.

This subject may preferably be divided into three sections, as follows:

(*a*) Generating apparatus.
(*b*) Transmission apparatus.
(*c*) Receiving apparatus.

(*a*) *Generating Apparatus.*—That no overload device should be used in the generating plant to disconnect disabled apparatus may be stated as a general proposition.

Experience has probably been responsible for the evolution of the art to a point where it has become not only possible, but necessary to eliminate all overload devices.

Only a brief statement of the reasons for abandoning the use of overload apparatus will be necessary.

In case of an accident to one generating unit, the other units in multiple with it will immediately begin to force current into the disabled one, and the increased load on the good units, due to their normal load plus the short-circuit current supplied to the crippled unit will, in all probability, trip all the circuit-breakers simultaneously, thus interrupting the service.

Without automatic circuit-breakers the overload on the good units would cause the potential of the system to fall so low that the service would, in all probability, be as completely interrupted as in the former case, unless the attendant succeeds in locating and disconnecting the crippled unit immediately.

Should he fail to do so, the service will inevitably be interrupted, and a great deal of damage done to the crippled unit by the current from the good machines.

It is then evidently necessary to have some means of discriminating between a current coming out of the machine and one going into it. Modern apparatus can safely carry 200 per cent. or more load for a few minutes, but if a unit has become crippled it will immediately cease to be a generator and become a receiver. All that is necessary to do then is to install on each generator a suitable circuit-breaker which will operate *only* when the direction of flow or energy through it is reversed.

This type of safety device has been developed for both D.C. and A.C. apparatus so that it operates quite satisfactorily.

As an additional precaution in large plants, a second reverse-current relay should be installed which will merely light up a letter or number in front of the operator so that in the event of the failure of the first automatic device the faulty machine may be quickly disconnected by hand. These reverse-current relays should have a time-element and current-limit attachment, which should be set for not less than three seconds, so that a slight reverse current, or one of momentary duration, such as is liable to occur at the moment of multiplying, will not operate the circuit-breaker.

(*b*) *Transmission.*—When transmitting power through overhead and underground cables, it is essential to successful operation to be able automatically to disconnect the feeders from (1) the generating station, and (2) if there are duplicate transmission lines, from the receiving station.

(1) At the generating station this should obviously be done by an overload circuit-breaker whose operation is delayed by a time-element which may be set at from one to ten seconds according to the local conditions.

This is all the protection necessary or desirable where only one transmission line exists.

(2) With two or more transmission lines in multiple, an entirely different set of conditions exist as in case trouble develops in one, current will be fed back from the receiver end into the fault through the good feeders; the result will be that all the feeder overload breakers at the generating station will trip, thus shutting down the entire line and, in all probability, shutting down all synchronous receivers on the system, due to the resultant fall in potential.

Reverse-current relays at the receiver end of the feeders operate satisfactorily, provided the fault is not severe enough to drop the potential.

If, however, the fault amounts to a short-circuit the potential at the receiver end will fall so low that the potential coil of the differentially-wound relay will not receive enough current to enable the relay to operate.

Reverse-current relays on the receiving end of feeders are not as yet to be depended upon, but recent improvements give promise that we may soon expect to find a satisfactory solution of this important problem.

When only two feeders are in use a method devised by Mr. L. Andrews, of England, seems to be very satisfactory. At the receiver end the two feeders are connected together through a choking-coil wound entirely in one direction. The current is drawn from a tap in the centre of this winding. Under normal conditions the feeders supply equal current through each half of the winding to the tap, but as the currents pass in reverse direction through the winding the resultant flux is *nil* and, therefore, the resultant inductance is *nil*, the only loss being that due to the ohmic resistance of the coils.

Should a short-circuit occur in one of the lines, the current from the other line will flow through both halves of the reactive coil in the same direction, thus producing a strong choking effect and limiting the current to an inconsiderable amount.

As the overload circuit-breaker on the faulty feeder at the generating station will trip immediately, it is then only necessary for the attendant at the receiving station to open-circuit the section of the reactive coil connected to the faulty cable and short-circuit the other half connected to the good cable. This device, I am informed, has given excellent results in England, but for obvious reasons would not be suitable for more than two feeders.

Where possible, the safest plan at present is, in the writer's opinion, to run the feeders entirely separate at the receiving end, only putting the D.C. end of the rotaries in multiple, or in cases where low tension alternating current (2000 volts or less) is supplied, putting the secondaries in multiple. If, under these conditions, reverse-current relays are installed at the receiving end of the feeders they will operate very satisfactorily as the reactance of the rotaries and transformers will be sufficient to limit the reverse current in the faulty cable, thus allowing the

reverse-current relays to operate as there has been no serious fall of potential.

The greater the number of feeders used between the generating station and the substation the better this method becomes, as, for instance, with two cables a fault in one will only reduce the capacity 50 per cent. until the operator can synchronize all the apparatus, which was running on the faulty cable, and as the apparatus and converters will continue to run at full speed only a few minutes will be necessary to synchronize on the good feeder, which will in the meantime carry the whole load, so that no interruption to service will occur. With three cables this would mean a loss of capacity of 33.3 per cent., and with four cables 25 per cent., etc.

(*c*) *Receiving Apparatus.*—This should be treated in exactly the same way as the generating apparatus, namely: use reverse-current relays *only* to operate the circuit-breakers on the rotaries, etc., and use time-element overload relays only on the low-tension feeders leaving the substation.

The above remarks apply generally to both D.C. and A.C. apparatus, with the exception of the part devoted to transmission apparatus, which, of course, only applies to A.C. transmission.

DISCUSSION OF H. G. STOTT'S PAPER ON "THE USE OF AUTOMATIC MEANS FOR DISCONNECTING DISABLED APPARATUS." BY W. F. WELLS.

MR. W. F. WELLS:—Recent experience with 6,600 volt, revolving field apparatus in central power station practice has proved that automatic disconnective devices are not necessary in order to insure reliable operation of the system to which current is supplied and that capable operators with good judgment can handle any cases that may arise better than automatic devices could be expected to operate.

The instruments and controlling devices on each generator should be placed close together, and their positions so related that there could be no possible chance of the operator when noting the indication on the instrument of one generator, becoming confused and by mistake opening the switch of another machine.

In the station referred to each generator is equipped with an overload relay whose secondary is connected to a red lamp only, and the following indicating instruments, wattmeter, power factor indicator, field ammeter, voltmeter and two ammeters.

The first indication of any trouble is generally a drop in bus pressure, unusual noise from the generators, or lighting up of the overload lamps. A quick survey of the instruments enables the operator to determine if the trouble is on the generators or feeders. If on the generators, the wattmeter or power-factor indicator shows if current is reversed in any one of them, and the field ammeter shows if the reversal is due to open field circuit or loss of motive power. The character of the swing or vibration of the needles will show whether the trouble is due to some accident affecting the angular velocity, such as break in valve motion, or if it is due to faulty governor, cut off of steam supply or broken vacuum.

After a short experience in any such station equipped similarly to the one mentioned, the operator is able almost immediately to locate the cause of the trouble, and if he thinks advisable, open the circuit-breakers before any automatic device would operate, if properly protected by a time-limit element.

During the past eighteen months eight generators have been operated a total of 25,000 hours and a careful anlaysis of every accident or mishap that has occurred has failed to show any necessity or even desirability of automatic disconnective devices. It is almost needless to add that the station was free from accidents that might have been caused by faulty operation of unreliable devices, and there was no expense incurred for maintenance and repairs of such devices.

In the transmission apparatus, it has been found best to set the time-limit overload relays on the feeders in the generating station for two seconds and at about two and one-half times normal load.

During the entire time that the station has been in operation, a period of nearly two years, it has always been the practice to

run the high-tension feeders on what Mr. Stott refers to in his paper as the safest plan; *i.e.*, entirely separate at the receiving end, only putting D. C. ends of the rotaries in multiple. But as practically all the substations are equipped with large storage batteries, which are also in multiple with the rotaries, it has been found best to operate without reversed-current relays, but depend on the operator in the substation opening the circuit-breakers when necessary. Here as well as in the generating station, the operators very quickly learn to read from their instruments the nature of the trouble, and the disturbance to the system caused by any accident is always less than it might have been had automatic devices been depended on.

In the substations, the receiving apparatus converts the alternating current to 260 volt direct current and here the only automatic device is an overload-relay on the high-tension feeders, and a centrifugal device which opens both alternating current and direct current switches of the rotary if its speed approaches too close to the danger limit. On the direct current feeders there are no automatic devices.

In general, on the entire system there are in use no automatic disconnective devices except those operated by the time overload relays on both ends of the high-tension feeders, and by the centrifugal speed limit device on the rotaries in the substations.

DISCUSSION OF H. G. STOTT'S PAPER BY MR. CARL SCHWARTZ.

MR. CARL SCHWARTZ:—As to the reverse-current relay for the generator circuit, I think that this relay should operate a lamp and then maybe in addition a bell signal in order to call the attention of the operator, so that he could take as quickly as possible suitable steps to bring the load back to the generator or disconnect this unit if it is unable to work. A reverse-current relay, opening the generator oil-switch, is in that case not very essential and could be left out entirely; but if it is applied it should be provided with a time and current-limit relay. The exciter generator circuit must contain a reverse-current circuit-breaker acting as soon as the generator begins to run as a motor, the supply of the generator field being maintained by a storage-battery.

Referring to the transmission lines, I would say that at the generator end, overload relays with a time limit device will be generally sufficient. It is important that the overload as well as the reverse-current devices for the feeder lines are connected to each phase, as burnouts between one conductor and the lead cover, not affecting the other phases of a three-conductor cable line, may occur. I refer here especially to the star-connected system.

DISCUSSION OF PHILIP TORCHIO'S PAPER ON "THE OPERATION AND MAINTENANCE OF HIGH-TENSION UNDERGROUND SYSTEMS," BY MR. EDWARD P. BURCH.

MR. EDWARD P. BURCH:—Referring to the testing of insulation of high-voltage cables, the writer would add his experience with

two very successful 12,000 volt three-phase cables, one 9.5 and one 7.0 miles long, used by a Minneapolis company for three and five years respectively.

Experiments were made on short lengths of these paper cables by stripping off the lead sheath and partly immersing them in water, the full potential being on the three legs of the tri-phase cable. It was found that it usually took several days before water impregnated the paper insulation to such an extent as to cause a short circuit between the legs.

Now most of the cable faults are due to mechanical causes such as a damaged lead sheath or to chemical deterioration of the sheath due to electrolysis from a direct current circuit. In both cases moisture finally, from a day to a week, works through the paper insulation and a cable break occurs. Manhole inspection for the exact location of electrolytic troubles generally proves valueless. Mechanical troubles at or between manholes are generally classed as " accidents."

Tests of value were regularly made on these 12,000 volt cables, using 600 volts direct current. The scheme is to charge the cable legs and then to note the electrostatic discharge through an ordinary Weston direct current voltmeter. The cable terminal switches were of course open at the station and at the sub-station. If the electrostatic discharge is large, one may safely conclude that the cable is not in bad condition. If the discharge as indicated by the swing of a voltmeter needle, is weak, this is due to the fact that the charge has leaked off through faulty insulation. The indications are, in general, reliable.

In railway power houses regular testing, between 2 and 5 A. M., thus furnished indications of the condition of the cables. It is of some real value to an operator to know that a certain cable is weak and may blow out.

Ground detectors sometimes give negative results. The indications on the scale of the commercial switchboard instrument are too rough to be of great value.

Cable testing sets of the D'Arsonval galvanometer type are generally too sensitive for power station work.

High-voltage tests of cables in service are considered of doubtful value.

DISCUSSION OF PHILIP TORCHIO'S PAPER ON " THE OPERATION AND MAINTENANCE OF HIGH-TENSION UNDERGROUND SYSTEMS," MR. W. G. CARLTON.

MR. W. G. CARLTON:—The experience of the Chicago Edison Company with its high-tension-three-phase cables has been similar to that of the New York Company mentioned by Mr. Torchio. At present they are operating about 45 miles of three conductor cable at 9,000 volts. The first of these cables was installed about five years ago. The voltage used at first was 4,500 but about one and one-half years ago it was changed to 9,000.

There have been seven cases of trouble on these cables: Four were caused by mechanical injuries to cables in manholes; one

by a burnout on an adjacent cable; one by a defective joint, and one by electrolysis causing a hole to be made in the lead sheath of the cable. With the exception of the defective joint none of these troubles would have been avoided by using high pressure tests on the cables.

The neutral points of the high-tension generators are grounded direct, no resistances being used to limit the flow of current. Two cases of trouble already referred to, one due to mechanical injury and one to electrolysis, resulted in one conductor of the cable burning to grcund, and the other two being left in good condition. One of these cases occurred within 3,000 feet of the generating station. The overload coils on the oil-switch worked and cut out the line. Rotaries in two large substations were running from this line but they merely dropped their load and did not feed back into the cable. Immediately after the trouble occurred the line tested clear and 9,000 volts was applied for about 10 minutes. When the trouble was located it was found that about 6 inches of the copper in one line was gone, and there was an irregular shaped hole in the lead approximately three by six inches.

The second case of trouble occurred about four miles from the generating station and was manifested by a motor generator operating from this line, making a peculiar noise. It was afterwards found that this was due to its running as a single-phase instead of a three-phase motor. The operator at the generating station had not noticed any trouble. One copper was found burned open and there was a hole in the lead approximately the size of a half dollar.

These two cases of trouble are possibly unusual in that very little damage was done. I believe however if we had been operating without a grounded neutral the chance would have been greater for more serious trouble owing to the displacement of the neutral that would have occurred.

PRESIDENT SCOTT:—We shall be pleased to hear from Mr. Eglin.

MR. WM. C. L. EGLIN:—Our experience is different from that of other large companies in that we use a higher frequency and as we started with 60 cycle rotaries before they were properly developed, it necessitated the use of direct current circuit-breakers on the direct side of the rotary converters, for the reason that these rotary converters were installed in stations with storage-batteries and also with other similiar units. With hand operation the current on the direct current side of the rotary would flash over before the operator had time to open the circuit-breaker, and with a large battery in the station it generally resulted in wrecking the rotary, at least wrecking the brush-holders. There were very few of the brush-holders left after that flashing took place; so that we have used circuit-breakers on the direct current side of all rotaries since that time. If we had machines with effective bridges it is possible we would not have

used the automatic circuit-breaker on the direct current side of the rotary.

The only other protective device is an automatic speed limit device to prevent speeding up beyond a predetermined speed.

One feature that I feel has not been discussed, and I was sorry it didn't have more discussion in connection with the paper last night, is the limiting of current on the high-tension feeder. I feel that with the growth of the size of generating stations and all of the feeders being run in parallel on a large generating station, we must provide some means for limiting the amount of energy that can be put in to any short circuit of a high-tension cable. Our own practice has been to subdivide the feeders at the substations so that at the substation ends the feeders were not tied together. I think our operation has been much more successful since this has been done. We had conditions similar to those that are spoken of by the high-tension people; that is, that we had the cables break down when they were tied together at the substation end, and a number of other cables would break down for some unexplained reason. Last winter we ran through with all of our cables separated at the other end, and if a cable broke down, that was the end of the trouble; no other cable would break down due to the disturbance in the line during the time of the short circuit.

MR. MAILLOUX:—I think that the customer sometimes has to combat the zeal of the manufacturer's sales agent in such matters. The importance of doing away with automatic control of the generators is, I think, such that it should not be under estimated or passed over lightly. It is of great importance in central stations, and it is even of greater importance in relatively large isolated plants. Perhaps the first attempt made to dispense with it in a large isolated plant was in connection with the Astoria Hotel nearly nine years ago. In laying out the plant there I foresaw that it would not do at all to have the machines become disconnected just as soon as we happened to have a little overload, and that it was necessary to resort to some other means of dealing with overloads. We first tried to raise the limit by putting on larger fuses, and we foresaw that cases might occur even where that would not do. We finally resorted to the expedient of putting in an overload-relay, which operated, not to cut out the dynamo but to put on a red light and ring a big bell, the effect being to call attention of all the attendants to the fact that there was danger, while the red light would show the particular dynamo that was overloaded. It was found in practice, however, that even that was not a desirable thing to do, because it might excite a panic. The apparatus is there, but it was never used and they now depend on the operators entirely. There is a man whose duty it is to stand by all the time and see to it that no panic occurs. If there is any overload it is better to let the machine run up to 100 per cent. overload, if necessary, rather than take chances of having a machine become cut out and

cause a serious panic. You understand that in a place like the Waldorf-Astoria, where the load is comparable to that of a small town, with from 20,000 to 30,000 incandescent lamps and a motor load varying from 500 to 1,000 h.p., it is a serious matter. I am pleased to say that in something like eight or nine years only one or two interruptions have occurred, and one of those was due to the breaking of a steam pipe.

MR. MERSHON:—I would like to hear further from Mr. Torchio or his representative, Mr. Wells, in regard to a number of points. One is in reference to his statement at the bottom of page 185, that only four cable breakdowns out of 18 faults in high tension cables could possibly have been due to defective installation. As far as anything in the table itself is concerned, it seems to me that nine of the faults there mentioned might have been shown by a voltage test. I should like to ask also whether it is the practice of the Edison Company to install cables and put them into service without giving them any more of a voltage test than one at normal voltage. In regard to the method, mentioned by Mr. Torchio, of keeping each set of apparatus consisting of cables, transformers, and converters separate and distinct until the direct current bus-bars were reached, it seems to me that condition is undesirable because of the fact that you do not get the benefit of your copper on low loads. Under such conditions you must, as your load diminishes and you cut out rotaries, and transformers, cut out also the cables to them so that you keep up to a certain point, a constant load loss on the cables that remain in service. I suppose that if it were possible to obtain a reverse circuit-breaker that could be depended upon to cut out a damaged cable, which would operate under very low voltage or at no voltage—it would be desirable to multiply the cables. I would like to ask Mr. Stott at this point whether he has gotten on the track of any such reverse relay, and whether he thinks there is any chance to have one in the future? His reply will, I hope, bring Mr. Gerry into the discussion, as Mr. Gerry expressed himself a while ago as confident that such device was obtainable. If there is such device I would like to know about it.

I would like to ask Mr. Fisher whether he has made any investigation of the rise in the temperature of cables due to the difficulty of getting the heat from the cable out into the ground; that is to say, as to the fall in temperature that is necessary to force a watt across a given amount of duct and into the ground; whether he has gotten any results which would enable one to calculate, in a duct system, what with a given distribution of load in the cables, the temperature would be of, say, a cable in middle duct. I tried to get some information of that sort a while ago, and went just far enough to get the information that would answer for the particular installation I was about to make. The results were not very full and referred to a conduit consisting of a very few ducts. I should also like to know whether Mr. Fisher has any definite figures on the actual temperature at the conductor which large paper cables will stand continuously without injury?

MR. MAILLOUX:—I think that the maximum voltage limit of cables is one of the important questions. I meet with that question constantly in my practice, in cases where one wishes to run overhead but comes to pieces of property where we cannot possibly get the right to run overhead. I have had such cases in districts where rich men live, who seriously object to having overhead wires of any kind pass by or near their properties. In one case it happened that my clients themselves are the people who most objected. They were stockholders of the company, and owned it, and yet, though they understood fully the importance of getting past, they did not want the lines run overhead. In some cases we have had to resort to very expensive underground construction in order to meet that difficulty. Now, as the radius of activity of such a station increases—as the territory expands on the outskirts—it becomes all the more important to be able to raise the voltage. I had a case which was started at 2,000 volts, which was intended to operate over a radius not exceeding two miles. At the end of two years we raised the potential to 6,000 volts and extended the radius to about 10 miles. We are now desirous of extending that radius to 25 miles. I may state incidentally that the station was designed for 500 kilowatts. It is now being transformed into a 6,000 kilowatt station. This gives you some idea of the growth of the system and of the difficulties which are likely to come up in connection with a station growing under those conditions. The problem with which we are confronted is, to what voltage shall we now step up? We shall probably operate at three voltages corresponding to three zones, a 2,000 volt zone, a 6,000 volt zone, which we already have, and a still higher zone. Now, shall that zone be 12,000, 15,000 or 20,000 volts? It seems to me that it is going to be limited by the limiting voltage at which I can get underground cables which will be reliable for good service. I have been told by some that these cables can be operated successfully at 10,000 volts; by others, as high as 20,000. I should like very much to hear from Mr. Mershon, from Mr. Fisher, and especially from central station men who have had experience with high-voltage cables. What is the highest voltage limit that we can now safely depend upon in cables?

MR. WALTER F. WELLS:—In reply to Mr. Mershon's question, I would say that it is the practice of the New York Company not to make over-voltage tests on cables; and this also applies generally speaking to all electrical apparatus. Apparatus as well as cables thoroughly tested before being installed. A test of a slight over-voltage, say 20 per cent. to 30 per cent., is enough to determine whether the work has been properly done or not.

As to the four faults referred to by Mr. Torchio, which might have been found by an over-voltage test originally, two of them were probably short bends in manholes. As to the other two, I am not well enough acquainted with the records to know which they were. They must have been some of the faults in splices.

Those shown by low insulation test evidently were good in the beginning and gradually deteriorated.

MR. MERSHON:—How about these faults designated as "in splice?"

MR. WELLS:—Those evidently were all right in the beginning and gradually deteriorated, whether due to external injury or not, I cannot say. Several companies operate in the same manholes, and sometimes the cables are roughly handled by employees of other companies or by contractors working on the Rapid Transit Subway excavations.

MR. STOTT:—In reference to the absence of tests on cables, I would say it is the practice of the company with which I am connected to make a 30 minute test of 100 per cent. over-voltage. That is to say, on the 11,000 volt cables which we operate, we would make a 30 minute test at 22,000 volts on the insulation between the three conductors and between the conductors and the ground. We find that a joint which is comparatively poor will stand up as long as 18 minutes and then break down, and in every case where we have broken down cables, with the 30 minute test, the result has been fully justified by what we found in the joints. Incidentally, I can perhaps throw a little light on Mr. Mailloux's question as to the reliability of cables. We have in operation on 11,000 volts, three-phase, over 120 miles of underground cable. Out of that 120 miles we have had only one fault in the cable itself. All the rest were due to inferior work in the joints; and I would say that since they went into operation 20 months ago, we have had a total of four breakdowns while operating. All the rest were taken care of in the over-potential tests. Out of the entire 120 miles there has only been one spot of weak cable. I think that is a very remarkable record and one that shows that 11,000 volts is an absolutely safe voltage. We have the feeling that 11,000 volts is a great deal easier to handle underground than 650 on a grounded return circuit, because you are very liable to get a very large current coming back through the lead covering.

On the grounded system, such as we operate, no matter how much copper you put in to bring back the current to the negative bus-bar, it is almost a physical impossibility to get enough copper in the street to reduce the drop below, say, 10 volts. The lead sheet of a cable 2⅝″ diameter has a resistance of approximately 1/10 of an ohm per thousand feet, so tnat a length of 500 feet subjected to 10 volts will give you something like 200 amperes in the lead sheath. We found by actual test that the lead sheet of such a cable, 2⅝″ external diameter, and the sheath itself being 9/64th inches thick, would only stand 400 amperes continuously until it reaches 100° C. rise. That of course was too high. I think that a great deal of the underground trouble has been due, not to faults in the insulation but to faults in the lead sheath. That is to say, stray currents from other properties have got back into that lead sheath and melted off the lead in spots where it touches

the hanger in the man hole. Of course, that admits moisture, and the insulation gradually deteriorates and breaks down.

Incidentally, I do not think it is worth while considering or discussing rubber-insulated cables at the present time, because the cost of a rubber cable is approximately 100 per cent. greater than that of a paper cable.

We have installed reverse-current relays in our substation feeders, but owing, as I said, to the fall in potential affecting the shunt coils, we found them entirely unreliable. That is to say, in case of short circuit in one feeder, the other feeders will all go out together, owing to the overload current carried by them through the substation to the break in the cable; so that whenever one feeder went up it invariably meant that the entire substation was shut down for a period of from two to five minutes, according to the number of rotaries that were running. Again, there is always a doubt existing in the mind of the operator as to which one of the five or six feeders was in trouble, as all the circuit-breakers went out at the power house, and it was very difficult for them to tell, without testing, which one was in trouble. I do not know how Mr. Wells' people operate in that way, but we found it absolutely impossible to determine which feeder was in trouble, as all the overload breakers went out simultaneously. To get around that, we simply separate the feeders at the substation so that each feeder supplies its own rotary. We have had short circuits on feeders since that change was made and the automatic apparatus took care of it perfectly without any interruption whatever to the service at the power house or substation. In fact, no one knew anything about it until the indicating lamps showed that the oil-switch had gone out. I believe a new device has been gotten up by one of the manufacturing companies which is really not a reverse current relay, but a system they have of causing one relay to lock the others. Suppose there are three or four feeders in multiple—the one which has the short circuit on it will evidently receive the greater amount of current. Therefore its solenoid will move up faster than the others, which are merely carrying the overload. As that one reaches the limiting point it closes a contact which locks all the other feeder relays in that substation. As soon as it breaks it trips its own circuit-breaker; then it releases all the other relays again. It is simply a little solenoid at right angles to the core of the primary solenoid, and it drags over the core so hard that it cannot move vertically. That has been laid out and is going to be installed on the underground division of the Interborough Rapid Transit Company, but I do not think it has been put into actual use up to date.

Mr. H. W. Fisher:—I will commence by answering Mr. Mershon's first question.

About two months ago I spent nearly five weeks with the Niagara Falls Power Company conducting experiments to determine the rise of temperature due to different currents on cables

laid in ducts. We experimented on different single conductor cables ranging from 3/0 to 1,250,000 c.m., and also on two and three conductor cables. The temperatures of the ducts at different points were determined by means of thermo-couples, consisting of rubber covered iron and German silver wires, all of which had previously been compared with a thermo-couple which we used as a kind of standard and the terminals of which we kept daily at the temperatures of ice and of boiling water. We also used resistance coils which had previously been calibrated to give the variation of resistance with temperature. Our experiments revealed the fact that there was a great deal of difference in the radiating power of different ducts; that the corner ducts radiate best, and the middle and top ducts become the hottest. Some tests made by the Niagara Falls Power Company revealed the fact that the top ducts were the hottest; an explanation of this is that there were openings here and there at points where the terra-cotta ducts were joined together, through which the heated air circulated in an upward direction.

Tests of different numbers of 1,250,000 c. m. cables showed that the rise in temperature of the duct when four cables were employed was 85 per cent. of what it was when eight cables were employed; and when two cables were employed the rise was 74 per cent. of what it was for eight cables.

The Niagara Falls Power Company is in some cases using water circulation in iron pipes to reduce the temperature of the ducts, and by so doing a reduction of 20° Centigrade was obtained in one case.

MR. MERSHON:—What is the maximum temperature that a cable will stand continually without injury to the insulation?

MR. FISHER:—I can say that 100° Centigrade continually applied to a paper cable will eventually deteriorate the paper, making it quite brittle.

I am conducting experiments along this line now to find out the maximum temperature which will not injure paper-covered cables.

With reference to Mr. Mailloux's question as to whether cables sold for a certain voltage could not be subjected to twice that voltage when it is desirable to raise the voltage in the generator plant, I would say that it is hardly fair to subject cables to a working pressure much in excess of what they are designed for. Whether this could be done or not would depend largely on the kind of cable and the voltage at which it was normally designed to work.

MR. MAILLOUX:—What is the highest voltage you have made them for?

MR. FISHER:—Cables are working now at about 22,000 volts.

MR. MAILLOUX:—Are they to be obtained under guarantee for that amount?

MR. FISHER:—Yes. By experience and experiment we are continually learning improved methods of manufacture and dis-

covering better insulating compounds, and for some time at least I think we will be able to supply what is likely to be required in the line of high-voltage cables.

MR. MAILLOUX:—You say 22,000 volt cables are commercially obtainable to-day?

MR. FISHER:—Yes.

MR. MAILLOUX:—That is what I wanted to know.

[COMMUNICATED AFTER ADJOURNMENT BY MR. W. L. WATERS.]

ELECTRIC CABLES FOR HIGH-VOLTAGE SERVICE.

I think the question of rubber vs. paper for high-tension cables is a commercial rather than an engineering question. Paper cables are simpler to manufacture, and hence are usually more reliable in practice, but I think there is nothing to choose as regards reliability between well-made rubber and well-made paper cables, provided they are lead covered.

I used to be connected with a firm which has probably had more experience than any other in the manufacture of rubber insulated cables, and we found that the chief points for reliability in rubber cables were good vulcanizing and keeping the rubber from contact with the air. No amount of text-book science will teach a man how to vulcanize a cable; it is an operation that can only be learned by experience. And if the men making the cables have not had this experience, the cables turned out by any firm will in all probability not be very reliable.

The rubber on a cable which is poorly vulcanized becomes rotten after being in service for a certain length of time, and it cracks and crumbles, especially when subjected to mechanical stress. When rubber is exposed to the air for any length of time, the sulphur apparently works out to the surface and oxidizes, forming sulphuric acid. This effect is more pronounced when the insulation is under electric stress on account of the formation of ozone, and is also more marked in a cable which is poorly vulcanized. The result in any case is the same, that the cable breaks down sooner or later.

In rubber cables, as in most other questions regarding the permanence of insulation, the purchaser is more or less at the mercy of the manufacturer, and I think that the cable manufacturer should receive his due share of the credit for a number of the mysterious breakdowns that we hear of on high-tension rubber cables.

DISCUSSION ON "USE OF AUTOMATIC MEANS FOR DISCONNECTING DISABLED APPARATUS."

MR. R. S. KELSCH:—A plant operated by the writer for five years, was equipped with expulsion type fuse blocks using aluminum fuses, on the eight 750 k.w. generators, and the same type of fuse on the eight 5000 volt transmission lines at both the receiving and the generating ends, and gave excellent results.

On one occasion the collector rings for the field leads of one of the generators short-circuited when the eight machines were operating in multiple. The disabled generator was dis-

connected from the system without the trouble being recorded on the recording voltmeter in the city substation.

On several occasions one or more of the lines were short-circuited by wire thrown on the transmission line, and on each occasion the disabled line was disconnected without interrupting the service. During the past year, relays have been employed and the fuses removed, and we have not had as good results.

Recently a dead short-circuit on one of the secondary circuits protected by a time-limit overload relay set for three seconds caused the potential of the system to fall so low that all power service was interrupted.

Reverse-current relays should be set to operate at five per cent. reverse current. Reverse current should not occur except under abnormal conditions and under these conditions, the apparatus protected by reverse-current relay, should be disconnected instantaneously, and should not have a time element attachment. A reverse-current relay so constructed would operate before the potential lowered sufficiently to make the relay inoperative. The only objection to setting a reverse-current relay to operate at five per cent. is the difficulty in synchronizing. This, however, can be obviated by synchronizing with the incoming generator pressure slightly above the bus pressure and the synchronizer indicating that the speed of the incoming generator is a trifle higher than the general system, which will insure the incoming machine acting as a generator the instant the switch is closed.

DR. F. A. C. PERRINE:—One question which has been touched on by a number of papers in this discussion, but which has not been specifically treated, is that of the proper subdivision of the lines for their protection from interference. The apparatus for line switching and line insulation has been treated for protection against lightning and the subdivision of the circuits has been considered, but it seems necessary to call attention to the fact that we have not, as yet, treated the question of dividing the line up into sections so that in case of accident the interference with the proper maintenance of supply by reason of the use of multiple lines shall not become excessive.

The importance of this was recently called to my attention by some calculations I have been making on a line 350 miles long, for which figures have been requested. If two lines were installed for this transmission, using such a size of copper as the question of economy would best warrant, the regulation, when only one of the two lines was in service, would be too bad for the proper supply of energy to the service. In consequence it was necessary to consider whether the size of line wire be increased or the line divided up in sections, which would permit cutting out only a short section in case of accident anywhere along the line.

In lines approaching 100 miles in length, the capital invested in each pole line is very considerable and in addition to the loss of energy which must be excessive if but one of the lines is in operation, there is a heavy capital charge during such times which must be carefully considered.

On most long-distance lines there are points of distribution along the line which naturally cut such a line up into sections and if switching stations are installed at these distribution points, permitting the transposition of the circuits, the effect desired can be accomplished but it is not always possible to rely on the fortuitous arrangement of switching stations. With increased length of line, there may be great distance between these switching stations, and furthermore the change-over switches operate under much more serious conditions when the sections they are controlling are long than when they are short.

It is true that up to the present time there has been a general tendency to avoid multiplying switching stations on account of the imperfection of high potential switching apparatus and the increased danger induced will be somewhat above the necessary imperfection of insulation in the switching apparatus itself. Such imperfection, however, is not a necessity and is one of the questions which must be solved in order to obtain satisfactory long distance transmission. This problem solved, the multiplication of switching points is feasible and this implies that with long lines, where two or three duplicate transmission circuits are established, it will become necessary to establish switching substations for no other purpose than the cutting out of sections in the line when repairs become necessary, thus obtaining satisfactory regulation, the efficient employment of the large amount of chemical which is necessarily employed in the transmission for great distances.

Such switching stations have been proposed as frequently as ten miles apart. The ordinary practice is not to install them more frequently than fifty miles apart. It is the writer's opinion that they should not be more distant than twenty-five miles, and their location at fifteen or twenty mile points would be more practical. Handling circuits at this short distance will be easier on the switching apparatus itself. Where switching stations are installed fifty or seventy-five miles apart, the high capacity of the line between switching stations increases the difficulty of switching, but even at the highest voltages, transposition switches can be installed with comparative ease, provided only, as I have already said, their insulation be sufficient to prevent concern for the safety of the circuit from this cause.

In connection with this question comes in the important problem of the use of automatic switching apparatus for such switching, and while the writer believes that the use of automatic switching apparatus be very advisable, at the same time we must recognize that at the present time the main problem of switching has not been so satisfactorily solved as to permit our consideration of automatic apparatus, however desirable it may be.

President Scott:—We have had to-day, according to a little account I have been keeping here, something like 75 contributions to the discussions on the papers which have been presented.

You will notice that the papers which have been presented, eight in number, are all by recognized experts in their several lines of work, and the discussions are from equally well-known men. Our Committee on High-Tension Transmission is to be very highly congratulated on what they have given us, and the response they have obtained.

A paper presented at the 185th Meeting of the American Institute of Electrical Engineers, New York, March 25, 1904.

THE RELATIVE FIRE-RISK OF OIL AND AIR-BLAST TRANSFORMERS.

BY E. W. RICE, JR.

Two types of transformers have been extensively used in electrical installations up to date, distinguished by the method of insulation and cooling employed. The "oil transformer" relies upon oil as the cooling and insulating fluid. The "air-blast transformer" contains insulation material mainly of cloth, paper, and wood impregnated with oil or varnish, and is cooled by the circulation of a blast of air. In both types the insulating material is of an inflammable nature, and under certain abnormal conditions may take fire with more or less serious consequences.

The electrical engineer must, therefore, consider carefully not only the relative but the actual fire-hazard which exists, and by proper and common-sense methods minimize such danger. Both types can be made entirely safe by correct methods of design and installation.

I think it will be admitted that in general that type which contains the greater quantity of inflammable material will occasion the greater fire-hazard. The inflammable material in an air-blast transformer of say 1000-kw. capacity will amount to about 800 lb.; in an oil-cooled transformer of the same capacity the amount will be about 7300 lb. While this comparison cannot be taken as a measure of the relative fire-risk, it is an indication to be considered, especially in view of the fluidity, the low temperature of ignition, and high calorific value of oil.

While the quantity of inflammable material in an air-blast transformer is, as stated, relatively small, it has an extended surface exposed to a large volume of air, and therefore, if a fire

starts from internal causes, such as short circuit or extreme overload, is capable of rapid combustion. This combustion could be checked by shutting off the flow of air to a transformer by means of a diaphragm automatically closed by the melting of a fusible link, the fusible link so located as to be melted by the first contact with flame; a method similar to that employed for closing fire-doors in buildings.

An oil transformer properly cooled is probably not particularly subject to ignition of the oil from internal burn-outs or arcs. It is well known that oil is an excellent medium for the smothering of alternating arcs, and this principle is utilized in connection with oil-switches. The vapor above the oil, may however, be ignited by electrical discharges. Even in this case, while the quantity of combustible material is enormous, the surface exposed is relatively small. The principle fire-hazard in an oil transformer is due to the large mass of inflammable liquid material which under certain conditions may become totally consumed. It becomes a special hazard in the case of fire from sources external to itself.

Considerations of first cost, economy of space, simplicity, operating costs, etc., have resulted in placing transformers in the same room with switchboards and other apparatus, such as synchronous converters, motor-generators, etc. Under such conditions, it would seem that the air-blast transformer constituted the lesser fire-risk than the oil transformer, and would therefore be generally employed if the fire-risk were the only consideration. The air-blast type, however, is limited in practice to pressures of about 30 000 to 35 000, as the static discharge which occurs at much higher pressures would in time break down the insulation. It is therefore necessary to employ oil insulation on the higher pressures now common.

The fire-risk can be practically eliminated by placing such transformers in a room or rooms separated by suitable fire walls from the other part of the plant. This plan has already been proposed and introduced. An entirely separate building, subdivided again into suitable rooms, may be employed where the maximum of safety is demanded. Much may be done to limit the risk, even when the transformers are placed in the same room with other apparatus, by proper systems of piping for draining the oil away from the building, by placing the transformers in a depressed area of concrete arranged for rapid drainage, etc. Of course any of the methods commonly employed for preventing,

limiting, or extinguishing oil fires may properly be employed.

In closing I wish to state that I consider a discussion of this subject both timely and important. It is well for engineers to consider carefully the dangers of all kinds, both to life and to property, that may exist in connection with the use of electrical appliances. The art is not advanced by ignoring or belittling the existence of real difficulties, but rather by intelligently facing the problems which occur and seeking a proper solution. Electrical energy is capable of being produced, handled, and transmitted more safely than any other form of energy, and such dangers as exist usually can be foreseen and safe remedies can be applied. On the other hand, we must not exaggerate the danger of fire from the use of transformers of either the oil or air-blast type. I believe the fire-hazard is extremely small, and can be and is being reduced to a negligible quantity by the adoption of methods similar to those I have outlined here.

DISCUSSION ON "THE RELATIVE FIRE-RISK OF OIL- AND AIR-BLAST TRANSFORMERS."

F. A. C. PERRINE:—As regards the question of the relative fire-risk of oil- and air-blast transformers, the speaker disagrees materially from the conclusions and from some of the premises that Mr. Rice has laid down. The experience of the Fire Underwriters and particularly the practice of Mutual Fire Insurance Companies shows that: "In general that type which contains the greater quantity of inflammable material will occasion the greater fire-hazard" is not generally admitted. On the contrary, the question which is most important is not of the quantity of inflammable material, but of its disposition. Modern mill construction is one which shows a very large quantity of inflammable material, but its disposition is such that the relative exposed surface is small, and this is the most important point. One question relating to the disposition of inflammable material is the presence of dust, not only in connection with the apparatus in question, but throughout the building. In the most important fires—of six or seven—the disastrous consequences have been due to the accumulation of dust. A small fire, where there is dust accumulated, will distribute that fire very widely. In consequence, it seems to me that the fusible link is a very poor protection against fire, because if flame occurs we have the consequent danger from dust. In one instance of a wooden shop a single flame shot out, followed along dust-covered wires, and set fire to all parts of the building, so that the operatives had barely time to escape, although there were doors at both ends and in the centre of the building. This shows the importance in all fire-risks of avoiding the first evidence of flame.

The writer also speaks of the protection that can be obtained by means of systems of piping for draining the oil away from the building and by placing the transformers in a depressed area of concrete arranged for rapid draining. In the speaker's experience there have been three very serious fires in which the transformers have suffered. In one case four 500-kw. transformers were installed on a wooden platform, each transformer containing 14 barrels of oil. The fire occurred by reason of a small arc at the failure of an unimportant low-pressure switch. The fire, by dust and varnish, was immediately conveyed to the woodwork supporting the switchboard and the transformers. When the woodwork burned away the transformers dumped over, the oil spread on the floor, and there was little left of the building or the transformers. A careful investigation was made at the time to ascertain whether the fire had been due at all to the transformers. Every foot of wire in the transformers was gone over by hand to find out whether there was the least evidence of an electric arc. Not only was there no evidence of arcing, but markings on the case were found indicating that so long as the transformers were in

place and the water circulated in the transformer coils, the oil had not even evaporated. There were markings on the cases which showed plainly the level of the oil, and the markings opposite the water-coils showed that the transformers had been sufficiently hot to char the oil opposite the coils inside the transformer, but not to evaporate any considerable quantity of the oil. In the second instance where transformers were involved, the fire was occasioned by reason of a severe short circuit, distributing a flame to the insulation of the wiring in the station and to certain woodwork supports of the switches and other apparatus. The transformers were standing on a smooth cement floor and were not disturbed. All combustible material in the entire plant was destroyed, but on account of the continuous circulation of water in the transformers during the entire fire the only combustibles in the building which did not burn were the oil-transformers, and to-day every coil in every transformer is in operation. The wires were led into the transformers through porcelain bushings, surrounded by wooden bushings simply for the mechanical protection of the porcelain. The wooden bushings were burned out, but the oil was not materially evaporated in the transformers. In one or two of the transformers about one quarter of the oil was evaporated and in these the transformer coils were covered with a black sediment, but on clearing this off the transformers were put into and are still in service, the coils not having been injured.

In another instance a short circuit occurring inside of a 500-kw. transformer, the station attendant maintained the short circuit until he could telephone to the superintendent and have him come to the station. For about 20 minutes black smoke was coming out through the insulation bushings on the case by reason of the actual fire and short circuit which was occurring under the oil in the transformers; there was no flame and no conflagration due to anything inside of the transformers. The oil was simply boiled away.

In a recent instance where a transformer house was destroyed by reason of an extensive wooden framework for wires above the transformers, the latter were also destroyed because the cases were made of thin metal soldered together, and the heat was great enough to unsolder the cases and spread the oil over the floor.

The conclusion to which the speaker arrived from these facts is that the safest transformer, as regards fire-risk, is the one in which the combustible material is so disposed as to present the least surface to fire, and that is the oil-filled transformer. As regards further protection, he believes it is an error to provide means for draining away the oil. On the contrary, for absolute safety the transformer should be installed in a cement pit which can be filled with water, but not above the level of the transformer, because if the water is flowed into the transformer the oil will run out and even oil on the surface of water will catch fire; but

if the transformers are installed in a pit, which can be filled with water from an outside source, the pit can be filled with water and automatically drained away without topping the transformer. The latter is so connected by pipes that no falling part of the building can destroy the water connection of the pipe-coils in the transformer. In this way there is secured the safest possible installation of the transformer. Furthermore in ordinary cases the pit arrangement is entirely unnecessary, if only the water connection be arranged outside of the building so that falling parts of the building cannot destroy the piping. A number of years ago at a meeting of the Pacific Coast Transmission Association, Mr. George P. Low, who is perhaps the best electrical insurance expert on the coast, called attention to the great danger in transformers which have thin cases and particularly those in which the cases are soldered together, because oil can be heated to the temperature which will melt solder without setting the oil on fire. Mr. Low recommended at that time to the insurance authorities that they prohibit the installation, where the building was insured, of a transformer in a case of thin metal, or where a part of a falling building could punch a hole in the metal of the soldered case, or where the soldered metal would melt. This is a wise position which he has taken, and as a consequence that transformer is safest against fire-risk which is an oil-filled transformer, water-cooled, and arranged so that the water can be kept in circulation no matter what happens to the building, and the case of the transformer is strong enough so that falling parts of the building will not puncture it. What the speaker refers to particularly is that when you have a fire which is not complete, and objects weighing 50 or 100 lb. may be falling, the case should be strong enough to withstand such impact and especially should be of such character and strong enough that the fire itself, from the outside, cannot, by melting the case or melting the solder, allow the oil to run out. With these provisions, the oil transformer is by far the safest transformer to install.

J. S. Peck:—The introduction to the discussion on this subject covers the matter in a brief but comprehensive manner, and the speaker is in substantial agreement with all of the statements made therein.

It has been the speaker's experience that the air-blast transformer is more much susceptible to damage by fire which may be caused by static discharges, arcs, bad contacts, etc., than is the oil-insulated transformer, but on account of the relatively small amount of combustible material in the former, and further as it is in solid and not in liquid form, it is possible to have such material entirely destroyed with comparatively little fire-risk to neighboring apparatus or buildings.

In the oil-insulated transformer there is a very much greater amount of combustible material, which, while less likely to take fire, increases the fire-risk to neighboring apparatus or buildings.

Under certain abnormal conditions, it is possible that the oil in a transformer may take fire, consequently it is essential that proper means be adopted for extinguishing the fire and for preventing damage to other apparatus.

There are two sources of danger from the use of oil in a transformer. First, the oil itself may take fire; secondly, a vapor is given off from hot oil, which when mixed with the proper proportion of air gives a highly explosive mixture. This may be ignited by a spark and cause serious damage to the apparatus, and even to the building in which it is contained. The first danger, that of ordinary burning, is fairly well understood: the oil being raised to a high temperature, takes fire, and so long as it can obtain a supply of oxygen, burns with an intense heat and gives off a very dense, black smoke.

The oil used in transformers has a comparatively high burning point (a fire-test of approximately 400° fahr.), and it is necessary that the oil be raised to this temperature before it can be ignited. On account of the large amount of oil in a transformer, it would be necessary to supply a great amount of heat and for some considerable length of time in order to raise the entire body of oil to the burning point,—a condition which rarely or never occurs. It is possible, however, to have local heating in the oil so that a very small portion of it may be raised to a dangerous temperature and this may then be ignited. This local burning, if not stopped, will gradually heat the neighboring portions and result in a general conflagration. Such local heating may be produced, for example, by an arc drawn just below the surface of the oil.

The nature of the second danger; that is, explosions, is not so generally understood. It has been found that with the best proportions of illuminating gas and air under atmospheric pressure the greatest pressure which can be obtained from an explosion is somewhat less than 100 lb. per square inch, and it is probable that with the best mixture of oil-vapor and air at atmospheric pressure, a force of more than 100 lb. per square inch cannot be obtained.

The speaker has made a number of tests on transformer cases with the view of determining the conditions under which combustion of the oil, and explosions of mixtures of oil-vapor and air may be obtained, also to determine the best methods of extinguishing the flames.

A sheet-iron case provided with a tight cover was used; the oil was brought to a burning temperature by means of an electric heater and then ignited by an arc at the surface of the oil. As long as the cover was removed from the case so that a fresh supply of air could be obtained, the oil would burn fiercely, giving off a dense, black smoke. Placing the cover on the case would almost instantly extinguish the flames. It was also found that a liquid chemical fire-extinguisher was very effective but did not act so quickly as the method of excluding the air.

As long as the oil was maintained at a temperature slightly above the fire-point no explosion was obtained, but when the oil was raised 30° to 50° above the fire-point, so that fumes were given off at a very rapid rate, it was possible to obtain an explosion which would lift the light sheet-iron cover several inches off the case. If it settled back over the case the flames would be immediately extinguished. This explosion could be obtained with almost every trial, but not unless the cover was first removed and a supply of air permitted to mix with the oil-vapor. From the nature of these explosions it was evident that the pressure per square inch at the time of the explosion was very small. The test was of a qualitative instead of a quantitative nature, and no attempt was made to find definitely the exact pressure generated.

In this connection, another instance is worth citing. A transformer which had been removed from the oil, and therefore thoroughly oil-soaked, took fire from a torch used for unsoldering a connection. In a few seconds the insulation was burning fiercely; the transformer was quickly replaced in the tank of oil, and the flames were immediately extinguished.

From these tests it is apparent that if a transformer case can be made reasonably air-tight, combustion of the oil cannot continue. Where it is possible to use a riveted boiler-iron case with cast-iron cover, it may be constructed so that it will readily withstand a pressure of 100 lb. per square inch, and if it is properly vented a pressure above atmospheric cannot be obtained before the explosion unless vapor should be given off from the oil at such a rate that its escape is throttled by the vent-pipe, an almost impossible condition with a vent-pipe of suitable size. Even if vapor is given off at such an enormous rate, it seems likely that the supply of air would be driven out from the case, so that the mixture left would have little or no explosive force. Where this type of construction can be used, it seems desirable to make the case of sufficient strength to withstand an internal pressure of 100 lb. per square inch with a reasonable factor of safety, and to provide a vent-pipe of suitable size. In such a case oil cannot burn, and should an explosion occur it can do no harm.

Where a self-cooling sheet-iron case is used, it is impossible to make it sufficiently strong to withstand an internal pressure of 100 lb. per square inch, and for such construction it seems best to make the case practically air-tight so that oil cannot burn in it, and to provide a large safety-valve which will be lifted in case of an explosion and will then automatically close, thus extinguishing the flames.

It is well to consider carefully all dangers, no matter how remote they may be. How remote is the danger from the oil-insulated transformer is shown by the fact that, although there are several thousands of them operating to-day, many of an old type and often installed without apparent thought of the

fire-risk, it is probable that the number of cases of serious trouble resulting from oil fires may be counted upon the fingers of one hand, and in the majority of these cases the trouble has started outside the transformer. In fact, the speaker knows of but one instance where the transformer was directly responsible for the trouble. This was the recent fire at Snoqualmie Falls, Washington, and as it bears directly on the matter under discussion, the following facts will be of interest:

The water-wheels and generators at Snoqualmie are located in a pit about 250 feet below the top of the falls. The raising transformers are located in a building at the top of the pit. There were twelve 550-kw. self-cooling transformers located in the same room.

The first indication of trouble was the melting of the insulation from the conductors leading to the transformers. When an attendant reached the transformer house one transformer was found to be on fire; this was extinguished by means of a Babcock extinguisher. It was then discovered that another transformer was on fire, but as the contents of the extinguisher had been exhausted and as there were no other means of extinguishing the flames, they soon burned through the wooden top covering the case, then melted the solder in the side of the case, thus permitting the burning oil to flow out upon the floor. The burning oil melted the solder in the seams of the other cases and permitted the additional oil to flow out. The conduits for the low-tension leads acted as a drain and carried the burning oil down into the wheel-pit, and for a time the whole plant was threatened with destruction. Fortunately the flames were extinguished without other loss than the transformer house, part of the transformers, and the low-pressure cables. This trouble at Snoqualmie Falls, taken in connection with other information concerning oil transformers, leads to certain conclusions:

1. Where practicable, the transformers should be placed in a boiler-iron case, capable of withstanding an internal pressure of 100 lb. per square inch, the case to be suitably vented.

2. Where a sheet-iron construction is necessary, the case should be made practically air-tight and provided with a very large safety-valve, so that an internal explosion cannot burst the case.

3. Provision should be made for rapidly drawing off the oil in case it becomes necessary to do so.

4. Individual transformer units, or groups of units should be located in fire-proof compartments, such compartments to be suitably drained so that in case the oil escapes from the cases it can flow out where it can do no harm.

5. Adequate means should be provided for extinguishing fire, and the station attendants should be trained to know what to do in case of emergency.

With such reasonable precautions the fire-risk to other apparatus from oil-insulated transformers will be no greater than

from air-blast transformers; with either type the fire-risk is practically negligible.

Dr Perrine has referred to the fire-risk of transformers mounted in cases made of sheet-metal, having seams riveted and soldered, and has pointed out the greater safety of the water-cooled transformer mounted in a boiler-iron case with seams riveted and caulked. Unfortunately this latter construction cannot be used on cases for large transformers of the self-cooling type; and as there is and will continue to be a great demand for self-cooling transformers it will be necessary to take such precautions in the installation as will reduce to a minimum the fire-risk resulting from cases of this type. It is, of course, recognized that a self-cooling case made without rivets and solder is to be greatly desired. It is hoped that a case of such construction may at some time be devised.

CALVERT TOWNLEY:—Strongly emphasized the fact that neither type of transformer constitutes a serious fire-hazard. He stated that such fire hazard as does exist should be divided into two classes; first, a source internal; secondly, a source external to the transformers themselves. The papers and most of the previous discussion has had to do with the internal source of fires, but if transformers themselves constitute a low fire-hazard the internal source is of minor importance. The chief danger from internal fire is perhaps the blast of air in an air-cooled transformer, which may carry internal fire to adjacent apparatus or to inflammable parts of the building. It is sometimes but not always possible or easy to place transformers so that the exhaust air will impinge only on non-combustible materials. An automatic device for shutting off the air, which may not be operated for several years, is not likely to work when it is necessary.

For a fire external to transformers the air-blast type is more subject to attack:

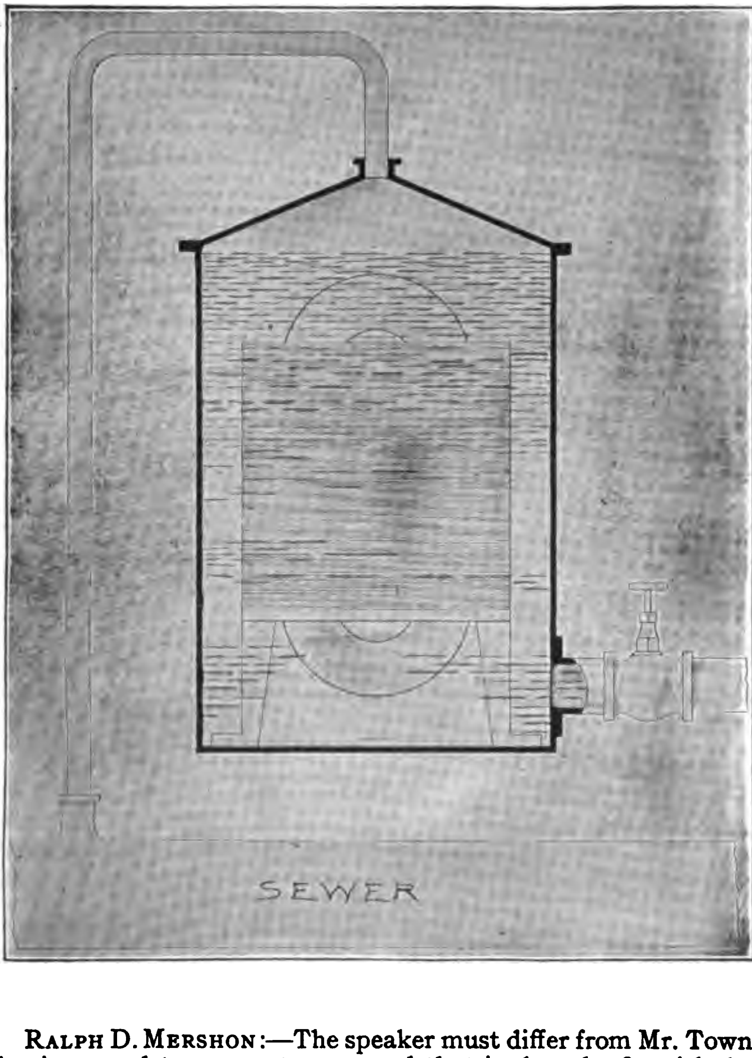
First, from flames, because it has no protecting case.

Secondly, from water, which, while it will not destroy, may put the transformer out of service for many days.

In a large installation, where both air-blast and oil-cooled transformers are installed in about equal capacities in the same transformer house, a somewhat severe fire occurred external to the transformers. The fire was extinguished after burning furiously for a time without damage to either type, but water completely soaked the air-blast transformers, which were out of service several days or until they became thoroughly dry, while the oil-cooled transformers were in use as soon as the connections could be re-established; that is, in a few hours.

Many people are misled as to the risk from oil-insulated transformers by the word " oil." That word suggests kerosene and the idea of very inflammable material, whereas oil of 400° fire test, such as is used for oil transformers, is far from an inflammable material at any but very high temperatures. A burning brand may be plunged into it and the fire will be extinguished.

Both types of transformer can be constructed and installed so that the fire-risk will be very small, and there is no reason why engineers or manufacturers should particularly favor the use of either type against the other.



RALPH D. MERSHON:—The speaker must differ from Mr. Townley in regard to one statement and that is that the fire-risk due to high pressures is greater than with lower pressures; if anything, the contrary is true. The speaker agrees with Dr. Perrine in regard to the relative fire-hazard, that it is not entirely de-

pendent on the amount of inflammable material, but is dependent more on the location and distribution of material. It also depends on the relative effectiveness of the provisions that can be taken for coping with fire. The scheme of installing oil transformers in separate rooms is not the best practice. In the case of high-pressure transformers it involves complications in wiring which are not advisable to use. The speaker is in favor of bare wiring for high pressures, and the moment you put these transformers in separate rooms you get into trouble with the high-pressure wiring. If the rooms are to be a thorough protection against fire they must be in the nature of vaults, which makes the wiring still more difficult. If the transformers are surrounded with fire-walls in a building of ordinary construction, and a transformer gets on fire, the transformer goes, and the oil may get away from you by the melting of the case.

In the case of an emergency such as might call for getting rid of the oil in the transformers, it seems a dangerous proceeding to draw the oil out of the case, when drawn out of the bottom, because in so doing air must get in at the top and there is a chance of an explosion, and that chance becomes greater as more oil is taken out of the case. This question of protection against fire has been carefully considered in the case of oil transformers, with reference to a plant of 50 000 volts and over, where the ultimate installation will mean transformers containing a good many hundred gallons of oil. The different methods of protection against fire were carefully considered and the scheme shown in the diagram finally adopted. The transformer case is built so that it will stand the maximum pressure which an explosion would cause, and all leads brought out through stuffing-boxes which will stand that pressure. To the middle of the top of the tank is brought a pipe running to the sewer and at the bottom of the transformer case is brought a water-pipe which has two valves in series, and between the two valves a drip cock to avoid any possibility of water leaking into the transformer through a leaky valve; the idea being in case of a fire emergency the water will be turned into the bottom of the transformer and drive the oil out at the top. No fire-walls have been installed in that plant although there will probably be some such walls between groups of transformers as an additional protection. As a last resort such an arrangement is about as safe as anything that can be thought of. Another advantage of this arrangement is that it leaves the whole space between the transformer free for a high-pressure wire, which can preferably be a bare one.

C. E. SKINNER:—An element to be considered in the oil transformer is the quality of the oil itself. It is extremely important that an oil be selected which has a flash-test considerably above the temperature at which the transformer will run in normal operation, including overload. At the present time a mineral oil is almost always used and can be obtained

with a great range of flash-tests. One having a flash-test not greatly above the normal operating temperature of the transformer will begin to give off fumes before the flash-point is reached, and these being explosive when mixed with air form a source of danger. An oil should be selected which has a flash-point not lower than, say 175° cent. Such an oil, if properly made, will have practically no evaporation whatever at 100°cent., this being higher than will be found except under the most extreme conditions of temporary overload. Too high a flash-test oil is undesirable on account of the viscosity being so great that the power to carry heat from the transformer to the cooler case is greatly reduced, and on account of its being unpleasant to handle.

Oil as a body cannot be set on fire easily; in fact a torch held to the surface of a body of oil will not set it on fire until the oil itself has reached the flashing temperature, or slightly higher. It is well known in the operation of oil-switches that an arc may be drawn under the surface of the oil and no fire results. This is true even though the temperature of the oil is above the flashing-point when such an arc is drawn, as air is absolutely necessary to the continued combustion of the oil. It is also true that an oil fire may be smothered with comparatively little difficulty, provided the oil is not allowed to spread. It is therefore obvious that a well-constructed fire-proof case with a cover which can be made practically air-tight, placed in a fire-proof compartment with means for draining, as mentioned by Mr. Rice, will reduce the fire-risk of oil-insulated transformers to a minimum. The great advantages of oil in insulating and cooling make it inadvisable on account of fire-risk to attempt to discard oil-insulated transformers, but to provide the necessary precautions to reduce this risk to the smallest possible amount.

H. G. Stott:—He thoroughly agrees with the view taken by Mr. Rice, that the fire-risk is absolutely proportional to the amount of inflammable material contained in a transformer. When the insurance inspector makes an inspection of the building upon which he is about to issue a policy, he does not merely look at the outside walls of the building but makes a most careful examination of the contents—and the rate depends greatly upon these contents—so that no matter what arguments may be used as to the method of quickly getting rid of the oil and preventing it from flowing out of the case, thus spreading the fire, it should be treated as an extra risk as compared to an air-cooled transformer. A number of instances of serious fires due to oil-cooled transformers have been mentioned to-night, but nothing whatsoever has been said of a fire due to an air-cooled transformer, and the speaker cannot recall ever having heard of such a case where damage was done externally to the transformer through fire communicated by it.

Referring to the general subject of fire-risks and efficiency

of apparatus, he desired to call attention to the importance of having skilled attendants in all power-plants and sub-stations. The difference in paying the men $2 00 a day or $3 00 a day is very small at the end of a year, but the skilled attendant at the higher price will invariably save many times the extra cost of his salary. It seems the height of folly to expend hundreds of thousands of dollars on the very best apparatus which can be bought and then, for the sake of saving a few hundred dollars a year, turn it over to be operated by men of no technical education or special training.

The very best automatic apparatus will soon become inoperative if not given the proper amount of skilled attention. In at least two cases mentioned to-night of fires by transformers due to melting of the solder on the cases, it is quite evident that had there been an attendant present with the requisite amount of knowledge the fire would certainly have been limited to the transformer which was in trouble, instead of destroying the whole station. When anything happens to electrical apparatus there is no time to telephone to any one for information as to what to do; the man on duty must be competent to take care of any emergency which may arise.

P. N. NUNN:—The fire-risk due to the oil transformer is not negligible. In a large, modern power-house filled with expensive apparatus the large amount of oil contained in a full equipment of oil transformers is a constant menace to the entire plant. This is shown by the present record of fires and by the average station record of accidents which might have caused fires. The risk to each transformer, due to accidents within itself, may not be serious, but the combined risk due to many such transformers is very serious, because it applies to the whole investment in the plant. While compelled for the present to use oil transformers, the conservative engineer, in designing high-pressure work, cannot afford to neglect or underestimate their danger, or fail to employ every reasonable precaution, even perhaps some extreme measures, for protection. On this account exception is taken to the spirit of some remarks made this evening. Their effect has been to discredit the importance of this risk, and the protective measures suggested.

Within a few years the Telluride Power Company has lost two complete sub-stations; and while the fires may not have originated in the transformers themselves, the loss suffered, of which the transformers were but a small part, was chiefly due to the oil. It is this danger, to which all surrounding apparatus is subjected by the oil transformer, which constitutes the chief argument against it in favor of the air-blast transformer.

It might be possible to use some highly insulating gas incapable of supporting combustion, which might be circulated, perhaps under pressure, through both transformer and cooling coil.

P. M. LINCOLN:—To start and sustain a fire two distinct ele-

ments are necessary; first, a combustible, and secondly, a supporter of combustion. Bearing this in mind, suppose we analyze the relative fire-risks of air-blast and oil-insulated transformers.

In the air-blast transformer we have present constantly and unavoidably both the essentials necessary to start and maintain a fire, the insulation of the transformer being the combustible and the cooling air the supporter of combustion. The only thing needful, therefore, to start a fire in the air-blast transformer is simply a sufficient amount of heat at any point. In this respect, however, the air-blast transformer does not differ from any other combustible structure, except that under normal conditions the supply of air is by forced draught.

On the other hand, when we come to examine the oil-insulated transformer we find a structure in which the combustible and the supporter of combustion are capable of being easily segregated by a fire-proof wall. Relative fire-risk is not simply a question of the relative amount of inflammable material as Mr. Rice intimates, but it must also involve the question of the probability of a fire being started. The oil transformer, although it contains a considerably larger amount of inflammable material, has the advantage of segregating this inflammable material so that it can be made almost impossible for a fire to start within the transformer, and can also be shielded from a fire outside of the transformer.

The speaker's only personal experience with a transformer fire has been with the air-blast type. This leads him to doubt the practicability of Mr. Rice's suggestion of a fusible link in connection with a damper to shut off the air. In the instance mentioned not only was it necessary to close the damper in the transformer but also to shut off the air and finally to turn the hose on the burning transformer.

In the speaker's opinion the greatest danger in the use of oil-insulated transformers comes from improper installation and consequent probability of the floor becoming oil-soaked. When properly installed, neither the air-blast nor the oil-insulated transformer involves a serious fire-hazard; but if compelled to choose between the two types the speaker would, for reasons set forth above, be inclined to choose the oil-insulated transformer.

C. L. de Muralt:—He does not agree with Mr Rice that the greater quantity of combustible in the oil transformers necessarily makes it a greater fire-risk. Transformers as a whole are not by any means the greatest fire-risk in any central station. In Europe, at least in Switzerland and France, the air-blast transformer is considered a considerably higher fire-risk than the oil transformer, and possibly for the following reasons: when air-blast transformers are overloaded, the insulation gets very much heated, and it is just possible that it breaks down somewhere, and takes fire either through the arc or through the heating of the insulation. In the oil transformer the oil forms, so to speak, a sort

of safety-valve, in that an overload will make itself felt only after a much longer time, when the other safety devices will probably have had time to come into play and cut the transformer out. This may be one of the reasons why air-cooled transformers in Europe are generally not used for sizes larger than about 150 kw. Oil transformers can be made almost fireproof, and it is a good plan to put them in separate buildings. This necessarily does not mean complication in the wiring. In the case of hydro-electric plants, which will mostly have to do with high pressures, the building is generally pretty long and narrow, with the units placed on one of the long sides. If the switchboard is placed in the centre of the other long side, it is easily possible to place the transformers in a room right back of that switchboard; similarly, if it is placed along one of the short sides; and in both cases the transformer room will probably not be much longer than the width of the main part of the central station. In both cases the leads from the generators will go to the switchboard, from the switchboard to the transformers, and as there need not be any switches in the high-pressure side of the transformers, they may go straight out. If the need for switches in the high-pressure side is felt, they can as well be placed in the transformer room and actuated mechanically from the switchboard. Thus, the line equipment will be, if anything, simpler than in the arrangement with the transformers in the central station itself.

In looking at the design which Mr. Mershon shows to-night, it would appear that when there is a necessity for flooding the transformers in order to bring the oil out, there is evidently a large fire, and every reason to suppose that the roof will come down and possibly break the oil piping which connects the transformers with the sewer. If this takes place, there may be serious danger of the oil doing more damage than if it had remained in the case. If transformers are located in a separate building, as just described, and placed in strong cast-iron boxes, or else in casings made of boiler-iron, riveted and caulked, and strengthened by angle-irons, and if these cases are well covered by a tight-fitting cast-iron cover, there is absolutely no fire-risk, either from the inside or from the outside, and such a transformer installation may be called as fire-proof as a brick wall.

O. S. Lyford, Jr.:—Before this discussion is closed more emphasis should be laid on a point raised by Mr. Townley. The title of the paper on transformers has naturally led to a discussion which gives the impression that these transformers constitute a very serious fire-risk. The fact cannot be emphasized too strongly, that although transformers are fire-risks these are not risks which cannot be successfully coped with. The speaker does not agree with Mr. Nunn as to the seriousness of the risk of the oil. This transformer subject ought to be separated into three heads instead of two; namely, the oil-insulated, water-cooled transformer; the oil-insulated, air-cooled

transformer; and the air-blast transformer. That they are all good should be emphasized. There is, however, a place for each type, as is usually the case with a number of good things of a similar character. Where water is available for cooling purposes, there is little question that the oil-insulated, water-cooled transformer is the type to be used. Where water is not available, the choice lies between the other two; but there is a distinct field for each. For instance, in a small sub-station, as in the case of an interurban railroad, there may perhaps be a couple of 250-kw. synchronous converters and an equipment of from three to six transformers of moderate size. In such a case the blower equipment is an unnecessary nuisance and the oil-insulated, self-cooling type has the advantage. On the other hand, in a large sub-station, such as one of those on Manhattan Island, there may be 20 transformers or more, and there is a gain by placing the transformers close to the synchronous converters and consequently distributing them throughout the building. Moreover with such a number of transformers the blower equipment is relatively a simple proposition, and all things considered, the advantages are in favor of the air-blast type. Therefore it seems to the speaker that a type of transformer for each specific service should be selected, and having done so it is perfectly possible so to design the plant that the risk of fire is extremely remote. In this day and generation it is seldom that we cannot afford to make a fire-proof building; many things besides transformers justify this precaution. The advantage of a fire-proof building was clearly demonstrated at Baltimore when practically the only two buildings left intact were the new power-station and the sub-station of the electric company, which were fire-proof; the fire could not get into the buildings. An electric plant costs so much money that the percentage added to make the building fire-proof is extremely small. With the surroundings fire-proof and the transformers properly located, the risk, as before stated, is extremely remote.

[COMMUNICATED BY LETTER.]

HOWARD BAYNE:—Mr. Rice's paper refers briefly to the necessity of employing proper means of preventing or extinguishing oil fires. In this connection the writer suggests the consideration of the use of steam as a means of putting out such fires. When properly applied, this has been found by those experienced in the oil business to be the best method of extinguishing an oil fire, particularly when the fire is serious.

Proper arrangements should be carefully planned and must be permanently installed. The transformers should be placed in a separate vault and in case of a large number they might be distributed among several vaults. Suppose each vault was equipped with one or more permanent two-inch steam lines, according to the amount of space in the vault. In case of fire, all outlets, such as doors and ventilators, should be closed and

the steam turned on. Both or either of these operations could be arranged to work automatically. The fire would be smothered in a very few minutes or possibly in less than a minute. The prime requisite is to have a large volume of steam turned into the vault quickly. If the fire is confined to the surface of the oil and the core and windings remain covered with oil, the transformer could be used again with very little, if any, delay.

The efficiency of steam in fighting oil fires is surprising. To illustrate: the company which the writer represents owned an large earthen storage tank at Gladys, Texas. It covered five acres and contained 200 000 bbl. of crude oil which was most inflammable since it gave off naptha vapors and hydrogen sulphide. On August 11, 1903, lightning struck the point of the conical roof. The small hatch at the apex was blown off and a tremendous blaze started. After several minutes the men got the hatch on again and turned steam into the tank. The blaze grew perceptibly less almost immediately, diminished rapidly, and finally went out.

The writer mentions this incident to show what can be done by smothering an oil fire with steam in a case where the fire has most favorable conditions for persisting. Compared to these conditions, those existing when oil in transformers catches fire would render the fire easy to extinguish. With oil-cooled transformers in "fire smothering" vaults the writer thinks the fire-risk would be almost nothing.

[COMMUNICATED BY LETTER.]

W. L. WATERS:—The question of the relative fire-risk of oil-cooled and air-blast transformers can be best decided by considering the different cases of transformers in stations with attendants, and transformers in stations without attendants. And also by considering fires due to internal causes and fires due to external causes.

Considering first fires due to internal causes. In an oil-cooled transformer it is almost impossible to start a fire due to a short circuit or a burn-out in the transformer itself, unless there is nearly unlimited power back of the short circuit. The oil will smother the fire so effectually that usually the mains will go before the transformer catches fire.

On the other hand, in an air-blast transformer a short circuit will turn the interior of the transformer into a blazing furnace, and even though the air supply is automatically cut off the transformer will certainly be totally destroyed unless it is cut out of the circuit. Whether the burning of the transformer itself starts a general fire depends, of course, on the arrangement of the building. If there are attendants present they can take care of the burn-out and can cut out the transformers before the situation gets serious.

In the case of an ordinary fire due to external causes the oil-cooled transformer will be completely protected from damage

by the oil, as the latter will not be heated to ignition point and will prevent the heat from reaching the transformer itself. An air-blast transformer in a similar case would probably be ruined, though it might not add much fuel to the conflagration.

In the case of a large fire, the oil in an oil-cooled transformer would be ignited, and on account of the large quantity of inflammable material the results would be disastrous. This might be prevented if attendants were present to draw off the oil, or if automatic arrangements were employed for draining the oil in case of fire. But, in any case an oil-cooled transformer is a very serious risk in a large fire.

Speaking generally, then, an air-blast transformer is at the mercy of almost every fire, no matter how started; and though a single transformer may not add much to the conflagration it will almost always be seriously damaged itself. On the other hand, an oil-cooled transformer is in practically no danger except in a large fire, and then the risk is serious. Generally a set of oil-insulated transformers will be a much safer installation than a corresponding set of air-blast transformers.

[Communicated by Letter.]

Irving A. Taylor:—It appears to be generally conceded that oil transformers are a greater fire-hazard than the air-blast type. Fire is not liable to start inside them, but in the case of an external fire the oil is liable to catch and produce a very hot fire. Internal short circuits are not likely to start a blaze, provided they are well under the surface of the oil, but if the latter is low, or the design is such that the coils are normally near the surface, an arc is liable to reach the surface, produce gas, and so set the oil on fire. The oil level should therefore be well above the coils.

In transformers which are sealed air-tight, a short circuit is likely to set up a sufficient explosive force to blow the cover off or to crack the case, the oil either running out or being thrown out—possibly on fire. Covers should therefore not be air-tight, but should prevent a circulation of the air. One of the greatest dangers from oil transformers is the fact that they are likely to leak under ordinary or extraordinary conditions. In the first instance, surrounding floors, whether of wood or concrete, become impregnated with oil and are very dangerous in the event of fire. Where cases are made of sheet-iron, or jointed with lead, an external fire is likely to open up the seams and let the oil out, with disastrous effect. All cases should positively be made of substantial cast-iron, without joints if possible. Where leaded joints are necessary, the lead should not be depended upon for holding the case together, and the latter should be fairly oil-tight without the lead.

Where oil transformers are used in large quantities they should, where possible, be installed in a thoroughly fire-proof building used exclusively for the purpose and isolated from other

buildings. They should not be placed in buildings like hotels, or in any room not thoroughly and heavily fireproofed.

It is sometimes desirable to install oil transformers where artificial cooling is not commercially feasible, or where water-cooling is more convenient than air-blast. Otherwise, where the pressure will permit, air-blast transformers are always cleaner in operation as well as safer, and their use is therefore more satisfactory.

Mr. Rice's proposal to use fusible links in air-blast transformers is highly practicable. They should be combined with air-tight dampers, and should be hooked in place so that the dampers may be worked periodically for inspection purposes. While such links would naturally be placed in the draught at the top of the transformer, it would seem that the dampers should be placed at the bottom so as to prevent burning material being dropped into the air chamber and in that way carried to the other transformers.

There should be no inflammable material, either in the path of the air-blast above the transformers or in the ducts, and the wiring should preferably be by lead cables enclosed in tile right up to the transformer. Where it is necessary to use rubber-covered wires at the cable heads in the ducts, they should be thoroughly fireproofed.

[Communicated by Letter.]

Norman T. Wilcox:—He believes that where properly installed, the fire-risk with oil transformers is not so great as many imagine. In two cases of fire started by lightning in the step-up transformers in the Canyon station of the Colorado Electric Power Co., he found that they were caused by an arc, which would not have occurred if the oil had been kept to its proper height in the transformer. There was some trouble in putting out the fire, especially on account of the gauze ventilators in the top of these transformers. In one case these spaces were blocked up with waste, which had been soaked in water, thereby choking off the air supply and smothering the flame. In the first case, the engineer of the station threw off the cover to the transformer, which resulted in a lively blaze. This was carried up the wires to the wooden framework almost directly over the transformers supporting the high-pressure circuit-breakers.

He would not use an air-blast transformer on high-pressure work if he could avoid it, as he believes that not only is the insulation better with oil, but the oil prevents the insulating material from baking, drying out, and cracking, and insures a longer life to the apparatus.

[Communicated by Letter.]

A. C. Pratt:—For maximum safety, oil-cooled transformers should be placed in a strong boiler-steel case, with the cover

well bolted on. The latter should have a relatively large flap opening to act as a safety-valve, so arranged that it will not of itself remain in the open position.

There seems to be no doubt that inflammable and explosive mixtures accumulate above the oil in transformers; but the self-closing cover will promptly smother any fire which might be started from this cause. These gaseous mixtures seem to be formed, at least in part, by minute brush discharges in the oil, which break up the mineral oil into light volatile constituents and heavy asphalt-like residue. These effects may be readily produced experimentally, even at pressures below 10 000 volts.

There should also be a considerable air-space to allow for a possible boiling of the oil without boiling over. Such a transformer will most naturallly be of the water-cooled variety, and will always be mounted on a fire-proof foundation. Risk from external fire should be small. A large body of oil in a substantial case, with relatively small exposed surface, will pass through a fire, such as would make scrap of an air-cooled transformer, and be ready for service in a day or two, upon renewal of leads and bushings. Incidentally the transformer cover should be water-proof to such an extent that water from a hose will not fall into the hot oil. As a final precaution, arrangements should be made to drain spilled oil away from the building.

[COMMUNICATED BY LETTER.]

H. A. LARDNER:—In the discussion as to the relative fire-risk of oil- and air-blast transformers, the opinion developed that large oil-cooled transformers in boiler-iron cases with suitable covers and vents were practically fire-proof, provided they could be suitably protected from intense heat from the outside. A suggestion was made that this class of transformers be installed in a pit which could be flooded to within a few inches of the top. While this gives the needed protection, it is an extremely inconvenient method of installation, owing to the necessity of occasionally moving the transformers. On account of the high-pressure connections overhead it is usually undesirable to have a crane in the transformer room, and the most common method is to mount the transformer on trucks so that they can be drawn out of their position and under a suitable lifting device in another part of the transformer house when repairs are necessary.

Naturally the installation of transformers in a pit will necessitate the use of a crane and is therefore objectionable. It occurs to the writer that, as transformers are usually arranged along one side of a room, they might be mounted on trucks as usual and a comparatively light boiler-iron tank installed around them. The back and possibly the two ends would be supported by the walls of the building while the front could easily be held in place by tie-rods. The tank should be provided with an overflow of ample capacity to prevent the water reaching

the leads, bushings, or running into the transformer case. The front of this tank should be made in sections so that a section could be removed and a transformer wheeled out to the repair room when desirable.

It would not be a serious fault if this tank were not entirely water-tight, as water would only be turned into it during a fire, and some leaking would not be objectionable.

The method of protecting transformers by submerging them in cooling water is believed to be good, as there can be no objection to turning water into the tank immediately upon an alarm of fire and the protection need not be left until a last resort. It also seems to be well established that, if the attendants will promptly disconnect a transformer on fire from internal causes and cooling water be applied externally to a suitable air-tight case, the internal fire will generally extinguish itself.

[COMMUNICATED BY LETTER.]

H. F. PARSHALL:—The experience gained in England would indicate that there is no great risk from either type of transformer so long as it is intelligently installed. It has been pretty fairly proved that the oil transformer is more reliable over a wide range of conditions. The principal advantage of the air transformer is in installations like the Central London Railway where an accident to an air transformer brings no risk to the working staff, whereas an accident to an oil transformer might bring about serious consequences. Where, however, the transformers can be installed so that no matter what the occurrence there is no danger to life, the oil transformer is, in the writer's judgment, to be preferred

[COMMUNICATED BY LETTER.]

R. S. KELSCH:—As regards the relative danger or risk in the use of oil- and air-blast transformers, the writer considers the use of oil transformers extremely dangerous, unless they are installed in isolated buildings. And even then, he would hesitate a long time before being responsible for the installation of several banks of transformers, with each transformer containing from five to thirty barrels of oil.

The writer has as yet been unable to obtain an oil transformer where the case was oil-tight, notwithstanding the fact that the contract specifically stated that in order to be accepted it must be oil-tight. The writer has visited many plants and has not seen an oil transformer that was free from leakage. As a rule, a large drip-pan was placed under the transformers, to catch the leaking oil.

In one instance three 70-kw. transformers for supplying power to induction motors were installed in a building, and during a thunder storm at 2 a.m. one of the transformers failed. After the fire the evidence showed that a short circuit had occurred at a point near the top of the transformer coils, burning a large

hole in one of the cases and allowing the oil to escape, catch on fire, and destroy all three transformers as well as the building.

In another instance, a plant in Montreal was supplied with 5000-volt, three-phase power from a water-power plant. There were three 150-kw. transformers for reducing the pressure to 2000 volts. The building and contents were of a temporary nature. A short circuit ignited the oil that had previously leaked from these transformer cases, and that which had been forced out of the cases by the heat and the entrance of water into the transformers. The entire contents of the building were destroyed, only the walls remaining standing. In this same building, having wooden floors and temporary switchboards, an air-blast transformer of 250-kw. connected solid to the bus-bars, fed by eight 750-kw. generators was completely destroyed. It burned for fully four minutes before the current was cut off, but did no damage outside of the transformer itself.

In another instance in Montreal, two 2000-kw. 25 000-volt, air-blast transformers failed. There were no automatic switches and in order to get the current off it was necessary to telephone the power-house to shut down. This required nearly two minutes, which would be time enough to burn a hole through an iron tank filled with oil and allow the oil, already ignited, to run over the floor; but in the case of these 2000-kw., air-blast transformers, there was absolutely no damage, except to the transformer itself.

From his experience with both types of large capacity, the writer would not use oil-filled transformers, unless compelled to do so. He does not imply, however, that an air-blast transformer in a frame building with a 12-ft. ceiling would be considered safe, but in making the comparison, he refers to the installation of transformers of large capacities in a modern fire-proof station. The danger in one case arising from the possibility of the flames due to the air-blast reaching inflammable material, as against oil escaping from the tank becoming ignited and covering the floor of the station with a sheet of fire. While the oil used in transformers does not ignite readily, and will permit a red-hot iron to be plunged into it without danger, a heavy short circuit will ignite the oil, and in these circumstances becomes a dangerous piece of apparatus.

The writer suggests that air-blast transformers be equipped with a positively air-tight damper to shut off the air. The damper generally furnished is practically useless in the event of the transformer failing, but he has had transformers equipped with dampers which were practically air-tight. The parts were, however, not rough castings, but consisted of a cast-iron frame with brass gates machined so as to make a perfect fit. They are operated by a key hung in a convenient place on the transformer. It may be argued that this introduces a possibility of damaging the transformer, but not to any greater degree than the use of a valve to let water into the transformer or to allow the oil to escape.

[COMMUNICATED BY LETTER.]

H. W. TOBEY:—Many engineers contend that air-blast transformers are the safer of the two types. The preference being due, the writer thinks, to two reasons: first, because the containing tanks of oil-insulated transformers have been made extremely light and constantly leak oil, and in case of fire will often open and allow the entire contents to escape; secondly, because of the use of a poor grade of oil. With substantial tanks and an oil having a high flashing-point, these two drawbacks are entirely removed.

The oil-insulated transformer is capable of withstanding severe and long-continued overloads without injury, while in the case of a short circuit within the winding it is entirely under oil and the arc will be extinguished before injuring more than a single coil. Leads coming from the various coils are always a source of danger unless carefully insulated and surrounded by oil.

Relatively to the ability of oil-insulated transformers to withstand fires due to external causes, the writer can instance an interesting experience of a large power company in the West. At the time of the accident, the transformer equipment consisted principally of a large number of 840-kw. units, all oil-insulated and water-cooled. These were arranged in groups of three each for stepping up from 2300 to 50 000 volts. A fire starting from some external cause spread to the transformer room where it burned for three-quarters of an hour. At the end of this time a pipe line above the power-plant was opened and the place was deluged with water for over eight hours. It would seem after treatment of this kind that little would be left of the transformers except scrap-iron and copper. On the contrary four transformers (which were somewhat beyond the hottest part of the fire) were put back into service without repairs. Others were dried out with current for a few hours and after being filled with new oil were also ready for service. There were only four which actually required repairing. On these the porcelain insulators had been entirely destroyed and the covers were badly cracked. The inside surface of the tanks, together with the coils and cores, were covered with a thick deposit of carbonized oil. A large amount of water had also gotten into the tanks.

The cores were taken down, the coils cleaned, and the outer layer of tape replaced with new. The parts were then reassembled and the transformers put back into service where they are still in successful operation. It is not difficult to imagine what would have become of this apparatus if it had not been immersed in oil.

This brings up an interesting question. Is it good practice, as many maintain, to empty oil-insulated transformers in case of fire?

[COMMUNICATED BY LETTER.]

WM. J. HAZARD:—In an oil-cooled transformer, seal the space above the oil as thoroughly as possible and provide an adjustable vent. Fill this air-space with some inert gas such as carbon dioxide, supplied by a gas generator which will automatically maintain a slight pressure, just sufficient to prevent the entrance of air to the case. The writer believes this would effectually prevent the ignition of the oil gases, and hence add to the safety of the apparatus. The extra complication and the cost of maintenance would be insignificant. The amount of gas necessary would of course depend on the rate of leakage.

[COMMUNICATED BY LETTER.]

E. P. ROBERTS:—In the matter of oil transformers, the practice of the firm with which the writer is connected has been for some time to place such transformers in a fire-proof room, believing that the fire-risk justified the slight additional expense. Our practice has been somewhat of an evolution. The Dayton & Northern power-house, designed in 1900, had a separate room built on the outside of the building and to one side of the generator room. This additional room was fire-proof construction with fire-door between same and the engine-room, with the floor on the same level as the latter. The one sub-station of this road had a fire-proof room built into the balance of the building, which consisted of a synchronous converter room, the fire-proof static transformer room, a storage-battery room, freight and passenger offices, and, above the latter, living rooms for the attendant. The floor of the static room was on the same level as the floor of the synchronous converter room.

In each static transformer room the high-pressure lightning arresters and switches were placed. Since then this has been modified, and for the Dayton & Muncie Traction Co., now under construction, the design is as follows:

For the power-house there is an addition to the building immediately in the rear of the switchboard. The addition has two floors and the whole is of fire-proof construction, using steel, brick, and concrete. The upper floor is on a level with the engine-floor level and herein are placed the high-pressure lightning arresters and switches, while there is a fire-proof door into the engine-room. The lower floor is below the level of the engine-room basement and has a fire-proof door from such basement. In this room are placed the static transformers. The floor is of concrete, with drains, and in case a transformer should catch fire and the oil escape, it will run into the drains and be smothered. But even if the drain should not take it off with sufficient rapidity, it could not run into any other room.

The additional cost of the building is slight, as, in any case, room must be provided for the transformers and high-pressure switches and arresters, and placing these immediately behind the board is convenient, and does not necessitate complication in wiring or in mechanism for controlling the switches.

The sub-stations, of which there are three, are two new buildings and one old one. The new buildings have fire-proof static-transformer rooms with wire towers; the floor is drained and is below the level of the other rooms, and a fire-proof door connects to the synchronous converter room.

The old building is a remodeled warehouse in the center of the town. The static transformers are placed in a fire-proof room in the basement and a tight brick shaft runs from this room to the third floor. The high-pressure wires entering the shaft through large tile ducts, which together with the shaft act as ventilators for the room in the basement, pass from the pole line down the shaft to the transformer room. Cold air is taken from an area way under the sidewalk.

The synchronous converters are placed on the first floor, on foundations extending into the basement and adjacent to the static room. The high-pressure lightning arresters and switches are placed in the static room, the switches being controlled from the switchboard in the synchronous converter room. This is not quite so convenient an arrangement for attention as the other sub-stations, but it is expected that it will prove satisfactory; it was necessitated by the local conditions and the decision of the engineers relative to placing the static transformers in independent fire-proof quarters.

[Communicated after Adjournment]

W. S. Moody:—Some of the gentlemen who have discussed Mr. Rice's paper seemed to have missed the real point which he brought out in this paper. He refers, not to the relative liability of fire orginating in the two types of transformers, nor even the question of relative damage which the transformer is likely to experience should fire develop in it, but the relative "fire-risk" of a *station* equipped with one or the other type of transformer. It is not necessary in considering this point to assume that one or the other type of transformer is inherently the safer or even that fire originates in the transformer at all. The simple question is, how much does the addition to a certain building of a certain small amount of inflammable material such as is contained in the air-blast transformers, increase the fire-risk on the building and contents as compared with the addition to the same building of transformers containing several hundred barrels of oil.

The question seems hardly to admit of discussion. The chances of a fire external to the transformer communicating itself to the interior is also slight. But granted a fire can originate somewhere and that it may set the insulating material on fire beyond control, then will not a few pounds of varnished wrappings constitute a perfectly negligible risk as compared with many barrels of oil?

[For further discussion on this paper see pages 269 and 279.]

A paper presented at the 185th Meeting of the American Institute of Electrical Engineers, New York, March 25th, 1904.

THE USE OF GROUP-SWITCHES IN LARGE POWER-PLANTS.

BY L. B. STILLWELL.

In a number of large electric generating plants recently designed in America, the feeder circuits are divided into a plurality of groups, and a switch designated a "group-switch" is connected into the circuit between the main bus-bars and each group of feeders. Obviously, no switch should be added to an organization of switch gear already very complicated and expensive, unless practical usefulness fully justifies its adoption. As this subject has never been discussed by the INSTITUTE, the writer avails himself of the opportunity presented by the invitation of the Chairman of your Transmission Committee to introduce it.

In considering a subject such as this, accurate generalization is difficult if not impossible. Probably no one who knows what engineering means would affirm without qualification either that he approves the use of group-switches or that he does not approve their use. There are few hard and fast rules in engineering. If such matters as the use or non-use of group-switches could be settled once for all, and for all plants regardless of size, function, or attendant conditions, the purchasing agent would soon succeed the engineer, the pharmacist would take the place of the physician, and the capitalist investing his money in electric power development and use would have no occasion to seek among technical advisers for sound judgment resting upon broad experience, and exercised in full knowledge of the existing state of the art, as well as recognition of its general direction and

tendency. Instead of attempting a generalization, therefore, we may consider more profitably the arguments for and against the group-switch in the case of a typical plant, and then glance at some of the modifications of function and circumstance which in the case of other plants would affect our conclusions. The group-switch first appeared in the plant of the New York Street Railway Company at 96th Street, but as the writer had nothing whatever to do with the design of that plant, he selects for consideration the plant of the Manhattan Railway Company.

In this plant two complete sets of main bus-bars are used. Switches are provided by means of which each of these sets may be divided into two independent sets of bus-bars to each of which four alternators and four groups of feeders may be connected. Eight group-switches are provided, through each of which current is supplied to a set of auxiliary bus-bars, to which in turn the individual feeders are connected through their respective switches. One of the eight feeder-groups is used to supply power to auxiliaries in the power-house. The other seven groups supply power, respectively, to the seven sub-stations which receive power from this central source. All switches in the high-pressure alternating-current circuits are of the motor-operated oil type.

The arguments in favor of the group-switch as used in the plant of the Manhattan Railway Company are:

1—It affords an additional means of opening a feeder-switch that may fail to open its circuit, when operated for that purpose. The advantages of the group-switch in respect to this function to-day appear materially less than they did five years ago, for the reason that the power-operated oil-switch within the period named has demonstrated a high degree of reliability. However, it cannot be assumed that the feeder-switch is invariably reliable, and, therefore, judgment of the weight of the argument in favor of the group-switch, based upon its use as a reserve for the feeder-switch, becomes a question of judgment of the chances of failure of the feeder-switch on the one hand and the seriousness of total interruption of power supply on the other.

2—It affords means of reducing aggregate load upon the power-house in case of necessity, more rapidly and otherwise less objectionably than the usual method of cutting off individual feeders. It will sometimes happen in the operation of a power-plant that it becomes necessary suddenly to shut down one of the generating units. If the load carried at the time be such

that the shutting down of the generator implies reduction of the external load, this can be accomplished most conveniently by operating one or two group-switches.

3—Where duplicate main bus-bars are used it facilitates transfer of load from one set to the other, in case it becomes necessary suddenly in operation to make such transfer. As bus-bars and connections are now installed in our best plants, this necessity does not arise frequently; nevertheless it is liable to occur, and obviously half a dozen group-switches may be used to effect the transfer in much less time than would be required were five or six times that number of individual feeder-switches used.

4—The grouping of the external feeder-circuits in group units bearing a simple fixed relation to the generator units establishes a symmetry and proportion most useful to the operator, particularly in times of emergency. In the case of the plant under consideration, at times of full load, the power passing through each group-switch is substantially equal to the output of one generating unit. This relation of course does not exist under partial loads, but under such loads it is not difficult usually to keep in service generating capacity exceeding the load by a margin sufficient to make it possible to shut down one generator without cutting off feeders; and in cases where this margin of capacity is not kept in service it is, nevertheless, a more speedy and certain operation to cut off the necessary number of groups of feeders than it would be to cut off a proportionate number of individual feeders.

The arguments against the group-switch are:

1—It introduces additional apparatus and, therefore, in itself increases the risk of interruption due to failure in switch insulation, etc. The successful operation of many plants, particularly in America, has been interfered with by the introduction of too much switch gear and too many safety devices, automatic and other; these additions in themselves being responsible in some cases for more trouble than they prevent; and it is to be noted that the group-switch implies the auxiliary bus-bar. Here again it is unwise to dogmatize, for as the result of additional experience the judgment of to-day may be reversed five years from now. As an expression of personal opinion, however, I may say that if the group-switch and the auxiliary bus-bars be reasonably well insulated and installed, the interruptions originating in this additional apparatus should be almost negligible in the case of such a plant as that which we are considering.

2—The group-switch and its bus-bars imply, of course, an increase in cost of the plant. In case of the Manhattan plant this increase is about 10% of the cost of the switch gear and measuring apparatus, and about four-tenths of one per cent of the cost of the plant. To put it another way, the cost of the group-switches and bus-bars for the plant approximates $20 000, and the annual cost, assuming this to be 10% of the investment cost, is $2000, which is about two-tenths of one per cent of the annual cost of operating the entire plant, including sub-stations.

In the plants in which the feeder unit equals or exceeds the dynamo unit of power, the group-switch, of course, disappears. In this case, however, it may still be advisable to use two feeder-switches in series in order to avoid the necessity of shutting down the entire plant in case of the failure of a single feeder-switch.

Obviously, also, there is no reason for attempting to use group-switches in cases where the total number of feeders is small.

For plants comparable in magnitude to the plant of the Manhattan Railway Company, using a very considerable number of feeders, the group-switch is important and its use generally advisable.

DISCUSSION ON THE USE OF GROUP-SWITCHES IN LARGE POWER-PLANTS.

ALEX DOW:—As to group-switches; the speaker considers that the separation of not only the feeders but generators into groups is now accepted as good practice. The drawing illustrating Mr. Stillwell's paper showed a condition normal in some plants but not representative of general practice. The accepted practice is, according to the speaker's observation, not to operate all the high-pressure generators in multiple but to separate the generators either individually or into groups and to give to each generator or group of generators its own group of feeders. The plant operated in multiple but only through the low-pressure distribution system—not on the high-pressure bus-bars; excepting, of course, that generators were put in multiple for the purpose of transferring load or taking machines in and out of circuit. The separation of generators and feeders into groups is indicated as advisable excepting where the transmission system has considerable resistance and inductance. A most notable exception which—like the tied-up air-switches—has also come recently under the speaker's observation is the Pacific Coast practice of running not merely several generators and feeders but several power-houses in multiple. The feeders and the tie-lines between power-houses are overhead and have high inductance, either natural or artificial. The frequency is high. Such a Pacific Coast system always "hangs on" to a short circuit. In one of these systems the established rule for dealing with a short circuit is to pull the field-switches of all synchronous apparatus—generators, synchronous converters, and motor-generators—excepting at one generating station. None of the apparatus is cut off from the system. The obvious result is that the remaining power-station has to supply a very large lagging current; the e.m.f. falls, and the short circuit breaks; whereupon the operators at the other power-stations and at the sub-stations re-excite the fields of their machines and normal conditions are re-established. A high-pressure system which can be dealt with in this manner has no occasion for group-switches. When, however, the conditions permit the concentration of a tremendous amount of energy on one fault, the group method is indicated and is already accepted as standard.

RALPH D. MERSHON:—The reasons given by Mr. Stillwell for the use of group-switches undoubtedly had great weight at the time the plants referred to were designed. That was when the oil-switch had not demonstrated its reliability, so thoroughly as it has now. In the present state of the art some of the reasons do not seem to stand very well. The oil-switches for pressures up to 10 000 which are constructed to-day seem at least as reliable, if not more so, than the apparatus which they control. If that is the case, it would seem that one is not justified in putting a number of switches in series. As regards the

ease with which the load can be thrown off the power-house, that can be taken care of by having tripping arrangements which will operate a group of switches which can be tripped at once. As regards the transferring from one set of bus-bars to another, there is a great advantage for the group-switch if the transferrence must be made quickly. If time can be taken to do it, a selector-switch might be used instead of two oil-switches.

H. G. STOTT:—Referring to Mr. Stillwell's paper upon group-switches, the speaker considers the group-switch as a species of insurance. The more valuable the contents of a house, the more insurance a man wants upon it and its contents; and in the same way the more expensive a plant is and the more important the service supplied by it, the more important it becomes to take every possible insurance against a shut-down due to any cause, as a shut-down of no matter how short a duration has a most disastrous moral effect upon the entire business connected with it. As a matter of actual experience of more than two years with over 160 oil-switches, the speaker has never yet had a single case where they failed to open the circuit when required. In some short circuits over 100 000 kw. were concentrated, so that certainly they have had a severe enough test to prove their reliability under all conditions. However, it would require a great deal of courage to advise leaving out group-switches in plants above 35 000-kw. capacity of generating apparatus.

In regard to Mr. Dow's statement as to the operation of plants without generators being in multiple or upon groups of feeders, the speaker does not know of any plant of any size that is operated in this way. In all large plants in New York City with the exception of the New York Edison Co., everything is operated in multiple. He believes the New York Edison Co. operates its station in two sections, but in each of these sections several generators are operated in multiple.

LEWIS B. STILLWELL:—In the discussion, two things had particularly attracted the speaker's attention. One was the remarkable short circuit Mr. Scott developed when he endeavored to induce Mr. Nunn to open an air-switch; the other was the interesting and original design which Mr. Mershon had adopted in the important plant at Montreal. This design the speaker considered well worthy of careful study, although he had not definitely formed his opinion in respect to it; it impressed him as being a substantial addition to engineering practice in the matter of oil-insulated transformers.

So far as the subject of group-switches was concerned, he was glad to know that Mr. Stott, who is now in responsible charge of the operation of the Manhattan plant, agreed with him in believing their use to be advisable. Obviously, their use or non-use depended primarily upon the degree of importance attached to an interruption of service and there was one

way to state the case in respect to the particular plant to which he had referred in his introduction which was perhaps stronger than any which he had used; viz., by comparing the annual cost of the auxiliary group-switches and their bus-bars with the revenue earned by the system in a short interval of time. As he had stated in the introduction, the cost of the group-switches with bus-bars is not over $2000 a year, allowing 5% for interest and 5% for maintenance, while the gross receipts of the system in rush hours often exceeds $5000 an hour. When the subject is looked at in this way, it is evident that the additional precaution is well taken. The speaker did not agree with Mr. Mershon in regard to the use of group-switches. The speaker understood Mr. Mershon to say that if by using a single switch for each feeder the risk of interruption of service by reason of switch failure was reduced to a point where it did not exceed the risk of interruption due to failure of the apparatus controlled, it would be unwise to double the switches. The speaker felt that this view was not correct and pointed out, for example, that if in a given plant using no group-switches six interruptions of service should occur in the course of a period of five years by reason of dynamo failures and six interruptions by reason of switch failures, it would be wise to use group-switches which might be reasonably expected to reduce the interruptions due to switch failure and so reduce the total interruptions of service.

[Communicated by Letter.]

William B. Jackson:—In determining the best arrangement of the switching equipment for a power-plant, two prime considerations and one of lesser importance must be the deciding factors. These are in order of importance: the reliability of service that may be expected from the system under consideration; the convenience and flexibility of operation; and the cost and depreciation of the equipment.

The use of duplicate bus-bars throughout electric power-plants as well as two single-throw selector-switches for transferring from one set of bus-bars to the other in place of one double-throw switch, has come to be recognized as standard construction.

No single arrangement of switching devices can be laid down as the perfect one for all plants. In general, however, the most reliable service is attained by bringing directly to the main bus-bars all of the generator and feeder circuits. Each circuit in this case should be supplied with a master-switch by which it can be disconnected independently of its two selector-switches. With such an arrangement of circuits no local accident which may occur beyond the main bus-bars and their connections can interfere with more than one circuit. Also no switch need be of greater capacity than that of its circuit. As the quantity of energy which must be handled by a switch has much to do with the reliability of its operation, this latter consideration is of im-

portance; especially as the individual circuits of large power-plants usually transmit as much power as can be conveniently handled by one switch.

In a group-switch arrangement as described by Mr. Stillwell the reliability of service is not so great as in the arrangement above described, since it introduces auxiliary bus-bars and associated connections, an accident to which will disturb the operation of all of the circuits in the group; also by the addition of currents of several circuits at the group-switch a troublesome switching problem is engendered.

By carrying each of the circuits directly to the bus-bars a more convenient and flexible system of switching can be arranged. The individual circuit, which is the natural unit of distribution, is duly recognized in this arrangement. By this system each circuit, whether it be a generator circuit or feeder circuit, has its own individual group of switches the operation of which will effect its connections alone, and it may be connected to either or both sets of bus-bars or disconnected therefrom with complete independence.

Although more switches are required for a reliable system for individual circuit control, yet the fact that each switch has to do with its own circuit alone permits of a switching system of great simplicity, and of perfect flexibility. The controlling table and instrument board can be arranged so that each circuit may have its own individual sections upon which all controlling levers, or switches, and all indicating instruments may be arranged so that the exact condition of the circuit can be instantly seen, from the observation of a single section.

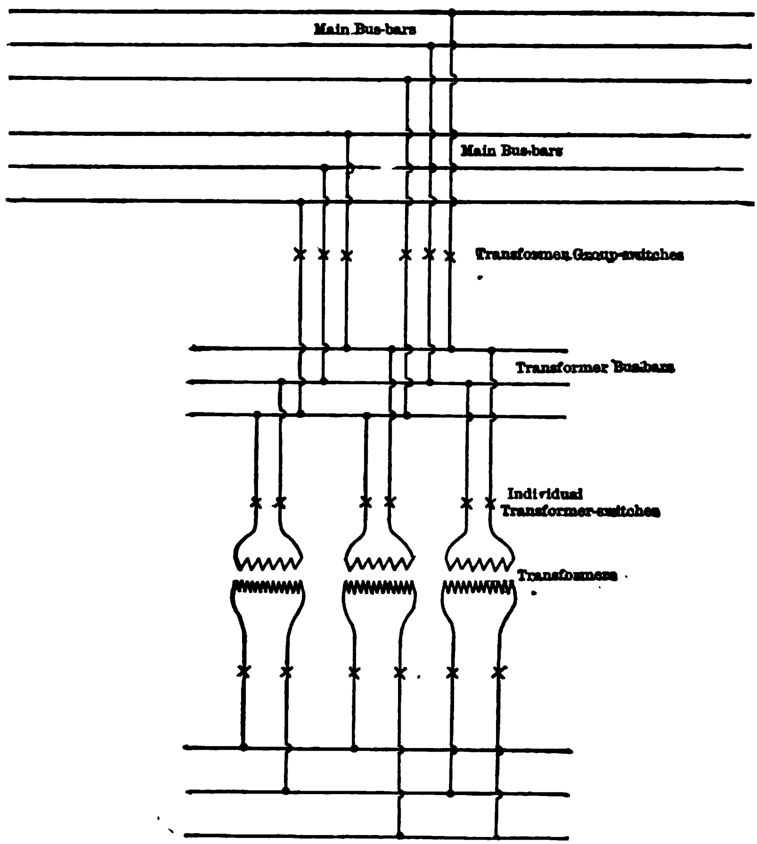
It is entirely unnecessary to use a group-switch system to permit of simultaneously disconnecting or transferring groups of circuits. With most of the methods of switch control, whether they be mechanical, electrical, or pneumatic, master-control can readily be arranged for operating the switches of two or more circuits simultaneously, while the several circuits still retain their individual control.

In the element of cost the use of a group-switch arrangement will usually reduce the actual first cost of the switching equipment as compared with a thoroughly reliable system where each feeder is brought to the bus-bars, owing to the greater number of switches that must be installed for the latter case. For instance in the arrangement described and illustrated by Mr. Stillwell, six circuits are handled by use of six single-throw circuit switches and two group-switches. To control six circuits where each circuit is brought to the bus-bars, twelve selector-switches and six master-switches would be used.

The matter of depreciation will also favor the group-switch arrangement owing to the less number of moving parts therein contained though this will not be so great as might be supposed, since it is necessary to introduce the higher-capacity switches in the group system as already referred to.

The cost of the switching devices required for any power-plant is exceedingly small as compared with the total cost of the plant, and a slight gain in reliability, ease and flexibility of operation will more than compensate for any added cost and depreciation that may be occasioned by the bringing of each circuit to the main bus-bars.

The plant referred to by Mr. Stillwell is an unusual case in which each set of feeders that are controlled by the group-



switches may apparently be considered, under ordinary circumstances, as a multiple-feeder carrying current to the same set of sub-station bus-bars. Under such conditions it would always be necessary to transfer all of these circuits simultaneously. It would seem that a more perfect result might be attained by arranging the system throughout so that all of these feeders would not of necessity be operated from the same set of main bus-bars.

In power-transmission plants, where step-up transformers are employed, a use of switches is made that may properly be considered in this discussion, but which is somewhat different from the group-switch arrangement described by Mr. Stillwell. In all plants where Δ-connected single-phase transformers are used it is desirable to be able to disconnect any one transformer without disturbing the others. Also, it is quite important that in changing from one set of bus-bars to another all of the transformers be transferred simultaneously. It is therefore quite desirable that the individual transformer circuits should be provided with their own disconnecting devices while transformer group-switches be arranged for transferring the Δ from one set of bus-bars to another. The arrangement is shown in the accompanying sketch.

Taking everything into consideration, it is the opinion of the writer that the arrangement of group-switches as described by Mr. Stillwell is one of limited usefulness, and that an arrangement wherein the individual circuits are brought directly to the main bus-bars is usually to be preferred.

[COMMUNICATED BY LETTER.]

IRVING A. TAYLOR:—Mr. Stillwell has enumerated, in very concise form, the several advantages in favor of group-switches. No. 1 is that they provide an additional means of breaking the circuit in case of failure in the feeder-switches. Nos. 2, 3, and 4 cover advantages of group operation.

It seems as though the latter class of advantages might be obtained as readily and more simply and cheaply by the use of multi-point control-switches, used in parallel with the ordinary ones; as group operation could be easily obtained in this way.

Advantage No. 1 was certainly very strong at the time the plants in question were designed, but, as Mr. Stillwell says, is not so important to-day, on account of the reliability of the oil-switch, but yet has some weight.

There are few plants, even of great magnitude, where a complete shut-down for five minutes (sufficient to clear a defective switch), once a year or two, is of sufficient importance to warrant the expenditure of several thousand dollars to prevent it. Probably large lighting companies, having a low-pressure network, are an exception to this, on account of the difficulty of starting up after a shut-down. With this exception, it looks very difficult to decide in favor of group-switching at this point of time, and this applies particularly, as inferred by Mr. Stillwell, as plants are smaller.

Another point that has to be considered in arranging feeder- or generator-switches is that few men of sound judgment would allow a man to touch lines, or even the coils of a generator, if an open oil-switch were the only thing between the man and death. The risk is not much; but life is too important to assume it. An oil-switch handle may be open, but one line may be

short-circuited in the switch, or the latter may be broken. Therefore, some kind of an air-switch should be provided in series with each feeder or generator oil-switch, for use on such occasions. An ordinary air-switch having short break, but provided with barriers, seems to be very proper for the generator circuit. On feeders, it seems as though a fuse-block could be used to advantage, as it will not cost materially more than the air-switches and will give additional means of automatically disconnecting the circuit, as well as fulfilling the above functions. In any case such switches or fuses should be installed between the bus-bars and the oil-switch.

Expulsion fuse-blocks with spring tension have proved to be very reliable on ordinary power and lighting circuits, provided they are occasionally inspected. It would be interesting to know whether such fuses are really reliable for breaking high currents to synchronous apparatus, as this is the worst possible condition. The writer understands that this fuse-block has not the same vital objection as the air-switch, in causing an abnormal rise of pressure or breaking the circuit. It may seem like a step backward to propose fuses, but if the objections noted are set aside, it would seem as if this were their proper field.

[COMMUNICATED BY LETTER.]

GILBERT WRIGHT:—The writer suggests that in place of the arrangement of group-switches, selector-switches, and busbars shown on the plan submitted by Mr. Stillwell, one set of main bus-bars be used instead of two, and that the feeders be tapped directly from this one set of bus-bars, the feeders to be controlled electrically, singly, and in groups. This method of control; that is, single and group, is very readily accomplished by installing one control-switch for each feeder and one master-switch for each group. This reduces the total number of switches by 32, eliminates one set of main bus-bars, eight sets of group bus-bars, with the necessary wiring between the switches and bus-bars.

Mr. Stillwell says that the group-switches and the group busbars in this station cost \$20 000. Estimating the cost of the 16 selector-switches for the generators and the extra set of main bus-bars, with the necessary wiring, to cost another \$20 000, would make a total saving of \$40 000. By spending, say, \$10 000 of this in improving the feeder-switches and in additional insulation and fireproofing of the main bus-bars and wiring, and on the additional control-wiring necessary to control the feeders singly and in groups, it is the writer's opinion that a greater factor of safety on the whole plant would result and that the same facility of handling changes in load would be obtained as by the plans described in Mr. Stillwell's paper.

The writer looks upon group-switches, duplicate bus-bars, and the necessarily complicated wiring for connecting same in the power-house, as so much insurance on the continuous opera-

tion of the plant; this insurance placed in small amounts, in a great many places and at a cost much too large in proportion to the results obtained. It will be seen that a possible saving of $30 000 could be made on this plant by the method described above.

The writer would suggest for general station practice to use as few switches, bus-bars, and as little wiring as possible, and make switches larger, more rugged, and with capacity to handle not once but many times the maximum load that they may under any conditions of service be called upon to handle.

[COMMUNICATED BY LETTER.]

JOHN B. TAYLOR:—The writer agrees entirely with the author of the paper, that no hard and fast rules can be laid down as to the conditions under which the use of the group-switch is, or is not, advisable. Apart from the question of mere additional cost, the following features in connection with the plant have some bearing on the matter:

(a) Pressure of the system.

(b) Number of cables or independent circuits supplying energy to each of the sub-stations.

(c) Liability of trouble occurring on any of the conductors or cables, requiring disconnection from the network.

(d) Reliability in operation of the high-pressure switching apparatus used, as shown by behavior of a number of switches in practical service.

(e) System of connection of low-pressure distribution; that is, with one sub-station out of service can cars be kept in operation adjacent to this sub-station, through power supplied by other sub-station?

(f) Character of service,—whether city work or interurban.

Taking up in order the various arguments given in the paper:

I. "Additional means of opening a feeder-switch that fails to open its circuit when operated for that purpose." The need of two switches in series for all circuits, both generators and feeders, connecting to the main bus-bars, must finally be largely a matter of personal opinion, based mainly on what the designer of a new system has observed or can learn from others regarding the behavior of the high-pressure switch it is proposed to use, under severe service conditions.

II. "It affords means of reducing aggregate load upon the power-house in case of necessity, more rapidly and otherwise less objectionably than the usual method of cutting off individual feeders." It is evidently advantageous to cut off all energy supply to a single sub-station without the necessity of locating and individually operating five or six controlling switches located at a greater or less distance from each other. While the use of the group-switch and the bus-bar gives the complete control of power supply to each sub-station through an individual switch, it should be noted that this same control could be obtained at

an expense extremely small, compared to the cost of a group-switch and additional bus-bar, by bringing to a central point the wires which control the opening of the feeder-switches. A single motion of a gang-switch would simultaneously open all of the four or five or more feeders supplying the sub-station to be cut out.

III. " Where duplicate main bus-bars are used, it facilitates transfer of load from one set to the other . . ." Obviously for the Manhattan station, fewer switches are necessary with the group bus-bar than would be required if two switches (one for each bus-bar) were supplied for each of the feeders. He thinks that in many plants the extra expense and complication of a duplicate bus is unnecessary and undesirable. In most cases, a single set of bus-bars, properly installed, with knife-blade disconnecting-switches, will be found cheaper, simpler, and quite as reliable. With very few exceptions, a spare bus-bar when installed is made use of only to allow men to work safely upon, or near, the regular bus-bar. The disconnecting-switches above referred to need occupy no additional space, and a judicious placing of same, to suit number of generators, number of feeders, character of load, etc., will permit cutting out a portion of the bus-bar, so that same may be handled with safety.

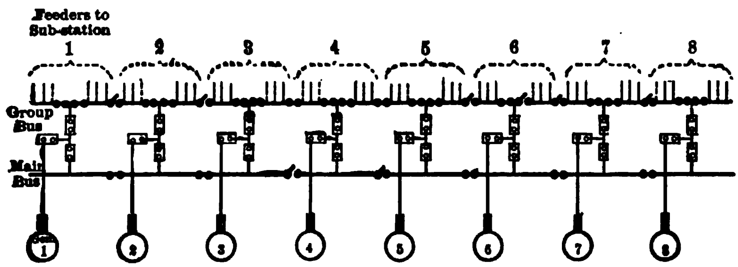
IV. " The grouping of the external feeder circuits in group units bearing a simple fixed relation to the generator units establishes a symmetry and proportion most useful to the operator, particularly in times of emergency." This symmetrical relation between number of generators and groups of feeders, is obviously not necessarily a general case, and while the proportion will hold more or less closely in most cases of city work, the relation between the number of generating units and outgoing feeders in a power-plant supplying an interurban system or a portion of a main trunk-line will be quite different. In the case of the city system, each sub-station is supplied by a number of independent cables, while in the general case of the interurban system or trunk-line, there are relatively very few feeders, which may supply several sub-stations, passing in and out of the stations intermediate between the generaing stations and the most distant sub-station. For service of this character, there could in many cases be but two groups, each consisting of the line either way from the power-plant. In the latter case, a group-switch is likely to be of very little benefit.

Regarding the two arguments cited by Mr. Stillwell against the use of the group-switch; that is, additional apparatus which may of itself increase the risk of interruption of service and the cost of installation and maintenance, the writer comments as follows:

The advantages to be gained through a complicated system of connections and switches equipped with all the various automatic and protective devices for overload and reversal in direction of energy transfer, with arrangements for instantaneous operation and adjustable time-limit, are always more plainly

evident on paper than in a plant in practical operation. It is better to err on the side of simplicity, giving the reduced amount of apparatus rigid inspection and attention, than to go to the other extreme of constructing a cumbersome switching arrangement, which is flexible only in theory, and confuses the operators in times of emergency by offering a number of possible combinations, each of which may be right, but no one of which is the only thing to be done, and that in a hurry.

Referring to the diagram of bus-bars and switches in the 74th Street station of the Manhattan Railway Company, it will be noted that each of the group bus-bars is fed at a single point and has no sectionalizing switches. Now this means that no work can be done on a group bus-bar without entirely shutting down a sub-station, and any trouble occurring on this bus-bar or on the connections between it and the switches, will cause a complete



CONNECTIONS OF SWITCHES AND BUS-BARS
FOR A
LARGE POWER PLANT

Knife disconnecting switch
High-pressure oil-switch

NOTE: A single conductor of three-phase system is shown in diagram

shut-down of a sub-station, until the trouble can be repaired or cleared. This criticism could easily be avoided by feeding the auxiliary bus-bar at the middle instead of at one end, and inserting knife-blade sectionalizing switches either side of the feeding point. Such an arrangement would permit the operation of the sub-station with half of the feeders, while work might be done on the other half of the group bus-bar. A still better arrangement would be to tap one of the group-switches at each end of the group bus-bar, knife disconnecting-switches being inserted in the middle of the group bus-bar.

In the accompanying sketch, the writer has drawn up an arrangement of switches and bus-bars which is essentially a single main bus-bar and a series of group bus-bars, which, however, may be interconnected to form a reserve main bus-bar in case of trouble or to facilitate work upon the main bus-bar. It will be noted that this

arrangement in its normal connection retains the group switch and also provides two switches in series between each generator and the bus-bar. The writer has shown the same number of generators and groups as are shown in the Manhattan diagram, and it will be noted that sixteen less high-pressure oil-switches are required. Oil-switches might be substituted for the knife-switches connecting the different group bus-bars and also in place of the knife sectionalizing-switches in the main bus-bar, but the writer considers the use of oil-switches at these points unnecessary.

[COMMUNICATED BY LETTER.]

H. F. PARSHALL:—So far as the writer is aware the only installation in Great Britain using group-switches is that of the Glasgow Corporation Tramways Department, the sole reason at the time being to safeguard against the failure of individual switches. With absolutely reliable switches there would be no possible advantage in such an arrangement. Granted that each switch safely and reliably controls its own circuit a duplication of switches is unnecessary and undesirable.

[For further discussion on this paper see pages 271, 280.

A paper presented at the 185th Meeting of the American Institute of Electrical Engineers, New York, March 25, 1904.

OIL-SWITCHES FOR HIGH PRESSURES.

BY E. M. HEWLETT.

This paper naturally compares the oil-break switch with the air-break switch. In treating this subject the following points appear to be the main points for consideration:

1—Abnormal Rise in Pressure: owing to the fact that in oil-switches the circuit is opened at the zero point of the wave, the rise of pressure found in the air-break switch is not experienced. This point is of particular importance in high-pressure, long-distance lines, and in cables carrying considerable energy.

2—Capacity: experience has proved that oil-switches may be designed to break circuits of practically unlimited capacity.

3—Length of Arc: owing to the smothering action of the oil on the arc the length of arc under oil is only a fraction of its length in air.

4—Insulation: the insulating qualities of the oil decrease the distance required to prevent leakage and arcing.

5—Size of Switch: owing to the fact that the arc length is materially decreased and the value of the oil as an insulation reduces the creeping surface, an oil-switch can be made very much more compact than an air-switch.

6—Remote Control: the design of the oil-switch lends itself readily to operation by control from a distance.

7—Arc Confined: the fact that the arc is ruptured under the oil within the switch has two advantages; 1st. switches can be placed close together without danger of short circuit; 2d. in case of emergency, confusion is avoided as there is no visible arc to disconcert the attendant.

8—Station Arrangement: the flexibility of the oil-switch places no limitations on the station arrangement, permitting the circuits and bus-bars to be arranged in the most advantageous manner.

9—Isolation of Phases: the possibility of complete isolation of the phases in a reasonable space is easily secured by the use of oil-switches

DISCUSSION ON "OIL-SWITCHES FOR HIGH PRESSURES."

C. C. CHESNEY:—(A) It is quite apparent that in the rapid evolution and in the perfecting of electrical machinery for power-stations, switch and switch-control design have been more or less neglected. On account of the great importance to all power stations of good switching mechanism, the reason for this neglect is rather difficult at this date to understand, although it is evidently more or less due to the apparent simplicity of a rather difficult problem. While dynamo, engine, and wheel design have been reduced to an almost exact science by the best talent of the engineering profession, the switch and the controlling mechanism have been refused the attention they deserve, although it may be safely stated that in power-stations of this country there are more shut-downs due to defective and inadequate switching mechanism than to any other one cause. Mr. E. W. Rice, several years ago in his paper on "High-Potential Control" pointed out the inadequate means at hand at that time for controlling and switching currents of large volume and pressure. In the same paper he described certain switches designed by the General Electric Co., which from extensive tests were believed would meet any and all requirements of heavy station-service. Since then these switches in actual service have fulfilled the designers' expectations. During the same period, the other manufacturing companies specially interested in high-pressure alternating-current machinery have developed high-pressure switches, on more or less different lines, which are believed to be equally good. However this may be, it can hardly be expected that the design of any of these switches is final and that there is no room for further improvement. The following notes are therefore offered in order to outline the more important features and essential elements which have made some of the later switches successful, but without any attempt to describe any particular make of switch or describe any particular switch design.

(B) Types: on American high-pressure transmission lines there are four general types of switches now in use:

1 Switches designed to break the circuit in the open air.

2 Switches designed to break the circuit in an enclosed air-space.

3 Switches designed to break the circuit with the aid of an enclosed metal fuse.

4 Switches designed to break the circuit under oil.

Type No. 1. The large amount of space required by this switch in order to be certain that the arc will be broken makes its use impossible except in rare instances and then it can be used with safety only when the line pressure is comparatively low, for the reason that a circuit containing inductance and capacity may have very high-pressure oscillations set up in it by an open air arc, unless the current is broken at zero value. The result of the increased pressure is likely to be the destruc-

tion of the insulation on some part of the system, probably that of the transformers.

Type No. 2. This switch is a decided improvement over Type No. 1, as far as the amount of space occupied is concerned, but its effect on circuits containing inductance and capacity is very little different from Type 1, so that there will be the same oscillatory rises of pressure and the same destruction of the insulation on opening the circuit. In addition, the explosion on opening heavy currents with this switch is at times so terrific as to endanger not only the switch itself, but all delicate instruments in the immediate neighborhood.

Type No. 3. Two forms of this switch has been more or less used. In the first form the fuse is connected in parallel, and in the second in series with the current carrying parts of the switch. The first form is limited to low-pressure circuits, because of the total unreliability of the enclosed fuse on comparatively high pressures when the circuit is fed from large central stations. The second form operates through the severing of a metal fuse within an enclosing tube filled with powdered carbonate of lime, or some other non-conducting powder. The end of the fuse is drawn through the tube by the moving arm of the switch and the circuit is opened without serious commotion if the switch has been well designed and care has been taken properly to fill the tube. The switch will open safely almost any circuit at almost any pressure, but like the open air-switch is limited by the amount of space required, while the powder set flying by the explosion of the arc is a decided objection if there is any moving machinery in the same room.

Type No. 4. This type of switch has within the past year been almost universally recognized as the only switch to be used for high-pressure work, for the reason that it can be made in compact form at reasonable cost and when properly built will disconnect from the generating system with certainty and safety any circuit under any condition of load, even a low resistance short circuit. Contrary to general expectations, it has been shown by a number of experiments that the opening of a circuit by an oil-switch is not a *quick break*; the oscillograph shows that the effect of the oil is to allow the arc to continue for several periods and then, as a rule, to break the current at the zero point of the wave. As a consequence, the opening of any circuit with oil-switches is rarely accompanied by destructive rises of pressure. The true reason for this fortunate action of the oil-switch is rather difficult to see. One prominent experimenter has attributed it to the " practical incompressibility of the oil, and, in consequence, the gas bubble which is formed at the terminals of the switch is under an enormous pressure and holds the arc up to the next zero value of the current. At the next zero value of current the liquid pressure blows out the arc." Another holds that by the breaking up of particles of oil by the arc, a high resistance conducting strata is formed

between the terminals of the switch, which allows the circuit gradually to discharge itself. It is probable that both of these phenomena may simultaneously enter into the action, because it is true that an oil-switch creates less fuss in the oil if it is opened slowly; but it is also true that an oil-switch for 40 000 or 50 000 volts must have a depth of oil over the terminals of at least four or five inches. If less depth of oil is used, the oil is likely to be thrown out of the oil pots, on the opening of the circuit, although the arc will be broken.

Of the two types of oil switches, used on 20 000,- 30 000-and 40 000-volt circuits, one, the plunger type, breaks the arc in a vertical plane, while the other breaks the arc in a horizontal plane. The plunger type has been used quite extensively in the larger power-stations of the East. The other form has been used more particularly by one or two of the larger Pacific Coast long-distance power-transmission companies. Some time ago the writer had an opportunity to test thoroughly a switch of the latter type on the circuits of the Bay Counties Power Company.

The switch was of the three-pole type and was arranged to break simultaneously the three legs of the three-phase circuit. During the regular running of the plant it had given satisfactory results under rather trying conditions. In order more thoroughly to test the arc-breaking qualities of the switch, one pole was connected across the main transmission line and the line was short-circuited at the full line pressure. The short circuit was then opened by one pole of this switch. As the switch was hand operated, there was no record of the exact time length of the short circuit, but it was not over one second. These experiments were repeated a number of times at both ends of the 150-mile line of the Bay Counties Power Company. Each time the circuit was opened without disturbance of any kind, and, as far as it could be determined, the short circuit was opened equally as well at either end of the line. During these experiments the Bay Counties Company were supplying their regular customers, and were operating at a line pressure between 45 000 and 46 000 volts. All of the alternating current generators at both power-houses were in operation and the output amounted to about 11 000 kw.

Fig. 1 shows one pole of this switch and gives the approximate dimensions. The mechanical construction of the switch is extremely simple. The contact-arm is mounted on an insulator at the end of the vertical operating rod. The outer ends of the contact arm carry fingers, which make contact with terminal-blocks on the ends of the studs which pass through the porcelain insulators to the line. It will be noted that each pole has two breaks in series, each about nine inches long. The switch was operated by rotating the operating rod which moved the contact arm through an angle about 90°. The oil-tank was 28 inches in diameter and there were about five inches of oil over the

contacts. During the test the cover of the switch was off so that the breaking of the arc could be observed. At each break there was a small arc formed at the terminal-blocks, but there was only a very slight elevation of the surface of oil immediately over the arc.

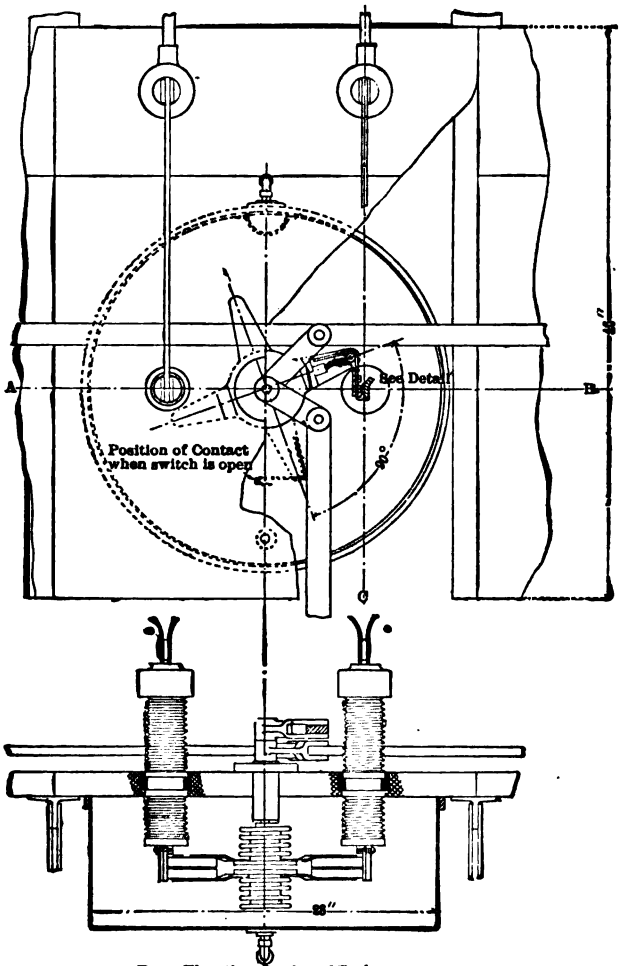


FIG. 1.

(C) On the assumption that the oil-switch, in the present state of the art, is the only switch to be used for high-pressure work, the following points of construction will bear consideration after the particular form of oil-switch has been selected:

1 Rating: The performance of the switch under abnormal conditions of a low resistance short circuit should be considered as well as the capacity of the switch under normal operating conditions.

2 Oil: Any good paraffine oil will answer, but it should have about the following characteristics:

Flashing point	215° cent.
Fire Test	250° cent.
Specific gravity	0.865
Viscosity	———
Acid	None.
Alkali	None.
Evaporation	Negligible.

3 Insulation: The insulators and insulating bushings should be either glass or porcelain. The switch should stand a breakdown test between the live parts and the metal case and framework of at least twice the working pressure. The external terminals should be far enough apart, or sufficiently well insulated, so that there can be no possibility of the current striking across through the air from terminal to terminal.

4 Location: Oil-switches should be placed away from the switchboard as well as the generating and transforming apparatus. Each pole should be placed in a separate fire-proof cell, so that by no possibility can an arc or explosion in one cell be communicated to another or to the neighboring machinery.

5 Method of Operation: All switches should be either magnetically or electrically controlled from a central switchboard, and all the poles of a switch should be operated simultaneously. It is also desirable to equip each switch, especially if it is automatic, with a time-element attachment, so that the circuit cannot be opened for at least a second after the operating mechanism is set in motion.

F. A. C. Perrine:—The speaker wishes to describe some experiments tried last fall with three oil-switches operating on the same principles as the one Mr. Chesney describes. The three switches were connected up at Mission San José in California, 98 miles from the power-plant of the Standard Electric Company, and the experiments were carried on during the night so that command of the entire generating station could be had. This station contained four 2000-kw. machines. A single handle controlled all three switches so that they opened simultaneously. The three-phase line was first connected through the switches, and the three phases short-circuited at the other side of the switches, thus putting a switch in series with each break. The line pressure was 40 000 volts. The switches were opened and closed about six or eight times that night. Then the work was shut down until the next night, when the switches operating as a short circuit between the wires of each phase could be connected, so that each switch formed a short circuit on a phase, the three

switches short circuiting the entire line, which is very much more severe service than in the former connection. The line was short-circuited and the switches were opened several times, first opening the switches quickly after they had been closed, and afterward holding them in short circuit. The switch operated successfully, the machines held the speed and the voltmeter showed the pressure was held up. The ammeters went off the scale at 12 500 kw. Finally the experiments were discontinued because at the power-house end of the line the lightning-arresters arced over. These were a series of the so-called Dutch-horn lightning-arresters which, especially for the experiments, were set 4.5 in., so that from line to line the gap was nine inches. The arc in almost every instance when we opened the switch went across these lightning-arresters and finally they were destroyed, the pole head was destroyed, and the No. 0 ground wire was entirely fused. The superintendent said that the appearance at the station was as though the sun had come down in the back yard. The interesting thing was that those switches did not fail to open the circuit on any one of the experiments, and the experiments were only discontinued on account of the danger to the generating and transformer apparatus due to the apparently high-pressure as shown by the current jumping across nine inches of open air space.

ALEX DOW:—In his opinion the oil-switch had definitely arrived—it was not merely coming. In Pacific Coast installations visited within the past thirty days he had found the air-break switches carefully tied up so they could not be operated; and in series with them, oil-break switches which were regularly used. This substitution of a nine-inch oil-break for a six-foot air-break was general on the Pacific Coast.

RALPH D. MERSHON:—Referring to Mr. Hewlett's paper, the speaker did not agree with Mr. Dow that the oil-switch has necessarily come. It has come for some pressures, but not necessarily as yet for 30 000, 40 000, or 50 000 volts, as any construction which in the present state of the art means going into cables with high pressures is objectionable. With such oil-switches as the speaker is familiar with, this is necessary or else a large amount of space for their wiring and installation becomes necessary. If an oil-switch could be put up in the roof truss of the building, being made as it were a part of the high-pressure conductors,—then it seems that the oil-switch would be a very advantageous piece of mechanism to use in connection with high-pressure plants, but until that is done it does not appear attractive.

C. F. SCOTT:—So much has been said about the oil-switch and so little that was favorable about the air-switch that the speaker thought of asking Mr. Nunn to say a few words on the subject. The air-switch a few years ago was introduced in high-pressure work when there was no oil-switch for that work, and it seems it still has a large field of its own in places where the

pressures are high and the amount of power, as for instance in small sub-stations, is small; where the oil-switch, as developed now, will be too expensive to install. In the first high-pressure plant of 40 000 volts, installed at Provo, Mr. Nunn had certain air-switches which it is understood rendered excellent service.

P. N. Nunn:—The impression is conveyed by Mr. Scott that a defence of the air-switch may be expected. The high-pressure air-switches at Provo are rapidly being replaced by oil-switches. This is in order to avoid the line disturbances caused by air-switches, and also in order to substitute the automatic feature of the oil-switch for the fuses necessary with air-switches. It is true that oil-switches are very expensive, but, while a reduction in cost will be most welcome, even at present prices, they will undoubtedly be used in all future high-pressure work.

C. L. de Muralt:—The speaker's firm uses both oil-type and air-type switches, the former in preference in all important installations, at least in the main leads. But there are cases where it would be very expensive to have oil-switches in every single place where the current may have to be interrupted at some time or other. Therefore, in places where such interruptions occur only once in a great while, or only in cases of an emergency, he sometimes, when economy is necessary, employs switches which resemble somewhat the horn-type of lightning-arrester. The main part is in fact built exactly like one of these lightning-arresters, the air-gap being bridged by a terminal part which, when the switch is actuated, is drawn away. The arc then breaks itself by drawing toward the upper ends of the horns, which are wider apart. The current of a 1500-kw. generator at 26 000 volts has been ruptured in this way, which is a fairly severe test. For oil-type switches he uses a switch which can either be manipulated manually or mechanically or automatically as a time-limit overload switch. The latter arrangement is as follows: the switch is held in position by a tripping device. If the latter is tripped a spring will open the switch. That tripping can be done either manually or by means of a magnet. The magnet in its turn can be energized either by directly closing a switch in the circuit providing it with current, or by a relay, the latter being actuated by overload currents. These currents set up in the relay a magnetic field which tends to turn an aluminum disc and the turning of this disc winds up a weight. As soon as the weight comes to its top position it closes the relay circuit. If the overload is very heavy the disc will revolve very fast, and thus the switch will be quickly released. If the overload is light, it may happen that it ceases before the weight reaches the top position and it will then re-descend and the switch will not be tripped. This constitutes an absolute time element overload relay, and makes out of the switch an ideal automatic circuit-breaker.

[COMMUNICATED BY LETTER.]

H. F. PARSHALL:—Before the perfection of the oil-switch, the air-switch with long break and large clearance for flaming was the most reliable device and many of the early installations owe their success to the use of the air-switch. Subsequent experience gained is that oil-break switches can be installed in a great deal less space and can be depended upon to open the circuit with much less damage to the switches. The one condition which his experience would lead him to impose in connection with oil-switches is that there must be absolutely no inflammable material in the switch other than the oil; that is to say, the use of wood and such like materials for separators and insulators is to be avoided.

In a brief written communication, A. R. Henry described a switchboard of the Canadian Electric Light Company's power-house, Chaudiere Falls, Quebec.

[For further discussion on this paper see page 275.

A paper presented at the 185th Meeting of the American Institute of Electrical Engineers, New York, March 25th, 1904.

TERMINALS AND BUSHINGS FOR HIGH-PRESSURE TRANSFORMERS.

BY WALTER S. MOODY.

This subject will include cables, straps, connectors, etc., for both high- and low-pressure side, designed both for terminal connections and for changes in the ratio of transformation, together with their insulation. In transformers for moderate pressure and having but two high- and low-pressure terminals, the problem of terminals is a simple one; with higher pressures and numerous changes in the ratio, however, the design of these parts of the transformer often becomes a most difficult problem, upon the proper solution of which depends, to no small extent, the reliability of the transformer.

Location of Terminals on Coils.

It is much better to have the high- and low-pressure terminals at opposite ends of the structure, for it is almost impossible to keep safe distances between the terminal and connecting coil leads when all are at one end. In a shell-type structure, having its coils in a vertical position, this requires one set of coil terminals to be at the bottom of the case, but to bring these safely to the top is not as difficult as to separate high- and low-pressure conductors that are at the same end of the windings.

Insulation of Terminals on Coils.

In an oil-immersed transformer, this presents little difficulty, as it is simply necessary to have all leads rigidly spaced a safe distance from each other and from the coils, and covered with sufficient waterproof insulation to prevent any moisture penetrating the coil around the terminals before the oil is put in.

In air-blast transformers, however, the case is different; here all terminals must be covered with an insulation integral with that on the coil itself, to a distance from the coil that provides sufficient surface insulation, even when the lead is well covered with dust and dirt.

Often the dielectric strength of a transformer is materially lowered by allowing the coil-terminals or taps to project beyond the sides of the coils, thus shortening the distance between primary and secondary. " Spreading " the exposed ends of the windings removes this difficulty, except when the terminal comes from a point well within the coil, but introduces a more serious defect, lack of rigidity to withstand the strains of short circuits. Usually the problem can be solved by so winding coils as to have only outside terminals and locating such coils as have taps on the outside of the coil structure.

Location of Main Terminals.

The best location for these naturally varies with the type of transformer and its pressure; for the air-blast type, the air-chamber forms a convenient and natural location for the low-pressure wiring, and the terminals of these are therefore usually located in the base of such transformers and made accessible by doors in the side of the base. For pressures not exceeding 25 000 volts, the high-pressure wiring can also be placed in the air-chamber, without making the air-chamber of excessive cross-section, so that all transformer terminals are in the base and exposed wiring is avoided. Heavy rubber-insulated cable is to be avoided in such construction, however, for should the rubber take fire from short circuit or other causes a draft of air will carry the fire rapidly along the duct and into the transformers.

In oil-filled transformers the terminals are, of necessity, located at or near the top of the case. Often for convenience in external wiring, projecting pockets are provided through which terminal-leads may leave the case in a downward direction. With such construction, it is necessary to have a solid section in the cable, just above the oil line, and to have this section insulated or covered with an insulation impervious to oil, otherwise the cable and insulation will act as a siphon and discharge oil.

Insulation of Main High-Pressure Terminals.

Below 40 000 volts, the insulation of terminals offers no special difficulty; porcelain or glass bushings can readily be obtained that are safe for this pressure, even if the conductor

has no insulating covering. For higher pressures, the problem is more difficult. If no insulation is used on conductor, the bushings become expensive and so large that there is scarcely room on top of a moderate size transformer for as many terminals as are often required. The following are some of the more common forms of bushings that have been used:

Wooden tubes;

Hard-rubber tubes;

Glass and porcelain tubes, both single and concentric;

Numerous forms of molded porcelain bushings.

Wooden tubes of the necessary size cannot be thoroughly dried and filled. Hard rubber is so apt to contain impurities that it is unsatisfactory; moreover, it deteriorates rapidly if ozone is generated near it. Glass is fragile and must be protected with other semi-insulators. Porcelain, or any smooth tube, must be very long if it have sufficient leakage surface to be safe when dirty, and even the best shapes of corrugated bushings are large and expensive when capable of withstanding a test of from 75 000 to 160 000 volts. All things considered, the writer has found the following practice quite satisfactory for test-pressures not exceeding 160 000 volts.

Insulate the lead with varnished wrappings that will safely withstand for one minute about half of the test-pressure to be applied, bringing out this lead through a porcelain bushing having the same strength as the insulation of the lead, and sufficient surface to prevent leakage at this pressure when dirty; in other words, let the insulation of the leads be sufficient for the working pressure, and the porcelain be of such strength as to give the factor of safety desired. This combination forms a far safer insulation than a bare conductor and a larger bushing which would stand the same puncture test as the combination, from the well-known fact that oxidized linseed oil is an insulation that will momentarily stand several times as much as it will for any considerable length of time, while porcelain, glass, etc., have no such time-factor.

In leads requiring a test of 100 000 volts or more, and insulated in this manner, an additional difficulty is met in the induced charge on the outer surface of the insulation; at this pressure the surface is covered with a heavy brush discharge that so reduces the surface resistance to leakage that 100 000 volts will travel along several feet. It is usually impracticable to make the insulated lead long enough to withstand the pressure under

these conditions, but the discharge may be broken up, so that it will not appreciably reduce the surface resistance, by bell-shaped pieces of rubber, porcelain, or other insulation slipped over the lead before all the varnished wrappings are put on, and having its small end so shaped as to allow of its being buried in the outer wrappings.

In transformers designed for Y-connection and grounded neutral, some transformer builders, in order to save expense on high-pressure bushings, have grounded one terminal on the case and insulated only such leads as are to be connected to the line; this prevents operation with Δ-connections, but otherwise seems unobjectionable. In similar manner, the use of three-phase transformers with the inter-connecting between the phases made within the case reduces the expense and possibility of trouble with bushings.

Eighty thousand volts is the highest pressure that is now practicable for transmission work, but transformers and insulators must be tested, consequently there is some demand for transformers working up to 200 000 volts. The insulation of the terminals of such transformers is the most formidable part of their design. As yet, I know of no satisfactory solution of the problem except to use oil-filled tubes as terminals. A terminal that has withstood 375 000 volts without any indication of weakness is constructed as follows:

The tube was the shape of two truncated cones, bases together; about 12 inches in diameter at the centre, and four inches at either end; it was built up of thin wooden rings, telescoped a short distance into each other, and held together by the conductor which, for mechanical purposes, was made quite heavy, and which was located in the axis of the cones and supported by washers at either end of the tube; between each section of the tube were collars of insulating material, some three inches larger in diameter than the tube, which served the purpose of greatly increasing the leakage surface. After the sections were drawn tightly together by nuts at each end of the conductor, the whole structure was repeatedly dipped in varnish and dried, thus sealing all joints. The terminal was mounted with the lower end several inches under the oil in the transformer and with its largest diameter on a level with the cover; the lower end of the tube was tightly sealed, making the tube perfectly oil-tight.

INTERNAL TERMINALS.

At present we are passing through a perioa of development in

line construction. Each engineer of a new transmission system of considerable length desires to use as high pressure as possible with a line construction of reasonable cost, but few are sure whether 50, 60, 70, or 80 thousand volts is the safe maximum for their conditions. It is common, therefore, for the manufacturers to be asked to make transformers that can be operated at several voltages on the high-pressure side. The result, whether accomplished with series-multiple connection, changing from Δ to Y, or simply by taps, usually requires so many terminals, that it becomes quite impracticable to place all the necessary leads outside of the case, even were it desirable to do so; consequently, accessible terminals inside the case must be provided. Again, at these and lower pressures also, it is usually desirable to provide for limited range of adjustment in the ratio, say by 2% steps, with a total of 10%; such changes are usually too small to be made except by means of taps on the high-pressure windings. Except in transformers of very large capacity, there would be no room safely to insulate so numerous terminals above the surface of the oil; the practice is therefore to locate such terminals just under the oil and make them as accessible as possible, either by the removal of the transformer top, or through an auxiliary cover on the top of the case. It is better that each of these terminals be separately supported by glass or porcelain insulators; for a single support, such as a slab of marble, is almost sure to collect sufficient semi-conducting material to cause trouble sooner or later. Such terminals being, at best, rather inaccessible there is danger that a wrong or imperfect connection will be made when changes are desired. The following method of mounting transformers in the tank greatly simplifies the problem of getting at such terminals, especially when transformers are installed under a crane: instead of supporting the transformer proper on the base of the case as usual, it is hung from a strong cover; the interior terminals are placed in about the usual position, but are supported by the bolts carrying the transformer. To get at these terminals it is then simply necessary to raise the cover with the transformer, until the terminals are on a level with top of case; connections may then be made with convenience and safety and the transformer returned to its position in the tank.

Low-Pressure Terminals.

Usually these present no special difficulties; when transformers are connected in multiple and deliver 500 amperes or

more, special caution should be taken that all joints are soldered or that terminals are of such construction as to have extremely low contact resistances. Taper plugs and receptacles are perhaps the most reliable form of contact for the purpose.

Current in excess of 500 amperes should never be brought out through separate openings in the case, otherwise there will be local heating around the terminal and needless reactance introduced into the circuit. Currents over 2500 amperes should be brought out by means of intermixed bus-bars for the same reason.

DISCUSSION ON "TERMINALS AND BUSHINGS FOR TRANSFORMERS."

RALPH D. MERSHON:—In Mr. Moody's paper there is one point in regard to the terminals for high-pressure transformers with which the speaker thoroughly agrees. The speaker considers that the marble terminal board has no place in high-pressure transformers. The leads should be brought out to porcelain insulators located underneath the oil, each to its separate insulator. In a number of cases troubles have occurred on marble terminal boards, at times too difficult to remedy. A marble terminal board scored by a discharge and afterward apparently made perfectly clean by scrubbing, will not stand the normal pressure when again put into service, and the only way in which it can be made to stand is to chip out the marble where the discharge occurred. Instead of using rubber-covered cables in air-blast transformers for high-pressure terminals, as Mr. Moody suggests, the speaker prefers to have these terminals come out into the air and remain bare during the rest of their course to the sub-station or the next bank of transformers.

C. E. SKINNER:—Every transformer designer who has had to do with pressures of 20 000 volts or over appreciates the difficulty of bringing out the high-pressure terminals from such transformers. It not infrequently happens in extra high-pressure work that the size of the transformer, and particularly the containing case, is materially modified by the requirements for bringing out the terminals. In the case of air-blast transformers pressures are limited by the tap to an amount which makes the problem comparatively simple, provided a large number of ratios have not been required to increase the flexibility of the system.

In the case of oil-insulated transformers the pressures have already gone as high as 55 000 volts in actual service, and higher pressures are now being seriously considered. As stated by Mr. Moody in his introduction to the discussion on this subject, these higher pressures present a very formidable problem to the designer, and this difficulty is sometimes still farther increased by the requirements for the transformer case to be able to withstand considerable mechanical pressure. Mr. Moody has mentioned some common forms of bushings, which have been used for the purpose of insulating the main high-pressure terminals. Wooden tubes alone are not satisfactory for pressures, which at the present time may be considered as high. Hard-rubber tubes deteriorate rapidly. Glass and porcelain are mechanically fragile, and it seems next to impossible to get a moulded porcelain of sufficient dimensions for some of the higher pressure now being required.

As a general proposition it is necessary for the higher pressures that the distance between the high-pressure conductor and the metal of the case, where the conductor passes through, must be of such a value and the material of such quality that there will be no appreciation brush discharge at this point. Where

the transformer tanks are not required to withstand heavy pressures a satisfactory construction consists in fastening a slab of insulating material, such as marble, in the top of the cast-iron cover into which are placed heavy tubes for the conductors with sufficient extension to give the necessary surface insulation. Tubes made up from alternate layers of varnished paper and mica have proved very effective. In one instance where the line voltage was 50 000 the transformer case was required to withstand a pressure of approximately 100 pounds per square inch. In this instance the marble slab mentioned above was not allowable on account of the mechanical pressure requirements and the problem was solved by making extra heavy bushings, which passed through stuffing-boxes arranged to clamp the tube very tightly. This has given excellent service.

An interesting example of bushing trouble occurred on a 55 000-volt line where the bushing consisted of a glass tube with 0.625-in. wall incased in a heavy wooden bushing for mechanical protection, the combination being set in a wooden cover. The static discharge over the surface of the glass tube scored the tube to a depth of 0.0312 in. to 0.0625 in., making the surface rough and finally a breakdown occurred directly through the tube, shattering it into many pieces. This shows that glass has a time-factor at extra-high pressures.

Mr. Moody mentions the complication frequently imposed in the construction of the transformer itself by requiring combinations for various pressures and for a slight amount of regulation by bringing out taps from the high-pressure windings. From the designer's standpoint the speaker wishes to protest against this practice of requiring almost universal flexibility. After the transformers are in service the operating man considers that the paramount idea is continuity of service. Every extra lead and tap complicates the design and makes the construction more expensive and difficult. It is possible, of course, to secure great flexibility by such means, but the chances of trouble from those leads and taps which are not in service, and the possibility of making a wrong connection, greatly increase, and it is the speaker's experience that in many cases where such elaborate systems are required they are never used.

[Communicated by Letter.]

Irving A. Taylor:—Instances have been noticed in air transformers where an uninsulated or lightly insulated tap is brought out through the external coil insulation and a lead soldered on and the joint insulated. This leaves a weak spot on the lead insulation just where it enters the coil insulation. Leads should be heavily insulated to a point well within the coil-jacket and should pass through the latter in a slanting rather than a straight direction, so as not to leave a vulnerable point in it at the point of entrance,

In some cases internal leads are brought up through the top

layers. This is a grave source of weakness as it gives a creeping surface through the inter-layer insulation. It also makes it necessary to wind the upper layers around it, and these are therefore liable to be crushed together. Taps from inner layers should always be brought out from the end of the layer, and in such a manner as not to cut the inter-layer insulation.

Where main terminals are located in the path of the air-blast, a great deal of surface dirt and consequently a long, creeping surface should be reckoned on. Terminal boards in air-blast transformers for this reason appear to be a source of danger, and where there are not many terminals it would seem best to use cables with heavy caps, the joints being made inside the case and above the fire-damper, if such is used. Fire-proof cables should be used in or near the air chamber.

Leads from oil transformers give a great deal of trouble by syphoning oil, and it is not at all easy to suggest a certain way of stopping it. Mr. Moody's remark that a solid section in the lead is necessary is correct; but it is difficult to insulate this section in practice so that the oil will not creep between the layers of insulation and on to the stranded cable. After a good deal of experimenting, the writer used a porcelain tube (filled with sulphur) over this solid section, and found it to be about the only successful method of stopping creepage. Bushings through the case should be extended well above the iron and the cable should be sealed in with non-solvent, insulating compound (sulphur may be used), so arranged as not to pocket any oil, but to drain it off. It is best not to have the braided covering of the lead extend inside the case as it is liable to carry oil out.

Where transformers are connected to outdoor leads they should have a solid section, well covered with water-proof material, in the external lead, as water will follow through a stranded cable for a long distance and in large quantities. This is a frequent source of burn-out in cable heads, etc.

All transformer cases should be grounded to prevent fire and make them safe to handle. Attention should be given to the fact that the ground wire should be heavy in proportion to the circuit protecting devices used. Thus, a No. 8 wire should not be used on transformers protected by 300-ampere fuses on the secondary side. The ground connection should be electrically sufficient and its resistance should be tested to determine this, a moderate pressure being used.

Where rubber-covered leads are used, the rubber should be heavy (not less than 0.25-in. wall per 10 000 volts) and of high quality, and fire-proof covering should also be employed. Extra flexible cable is usually preferable.

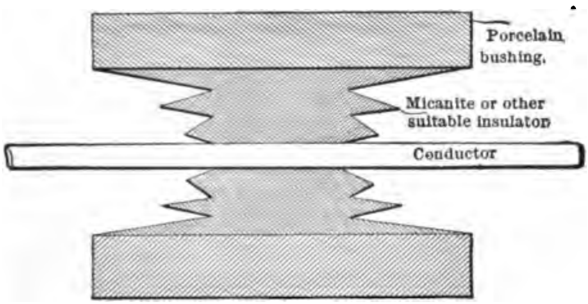
While taps allow one of the greatest advantages of the transformer to be utilized—that of obtaining different pressures from the same apparatus—it seems as though many specifications require more taps than are actually necessary. Taps cost money

on account of the necessary space, and besides are nearly always a source of weakness. They should therefore be avoided unless their use is absolutely justified. Except where transformers are to be used partly as pressure regulators, one 5% or 10% tap should give sufficient adjustment of ratio to meet lighting or railway conditions. Mr. Moody's remarks regarding the use of separate porcelain insulators instead of terminal boards are entirely correct. The writer thinks that the necessity of using a crane and taking a transformer apart to change or make internal connections, is hardly justified. Transformers should always be tested before connecting to their bank to discover wrong connections.

[Communicated by Letter.]

N. M. Snyder:—The writer suggests that the design of the high-pressure insulator be drawn on—for meeting the conditions—without resorting to the oil-filled tubes for high-pressure terminals. First by making a suitable insulator for the glazed porcelain bushing, *e.g.*, to fit inside, having the conductor passing through its centre.

The insulator being double petticoated as the cut shows, gives a much greater resistance path than the straight bushing.



Side elevation cross-section showing insulator and bushing.

In bringing out heavy currents from transformers in multiple he concurs with the idea of sub-division of terminals, while it may introduce the necessity of more openings it has the advantage of distributing the load more evenly on the windings, assures less local heating and greater terminal surface for cooling.

[Communicated by Letter.]

A. C. Pratt:—In considering the location of internal terminals in transformers one point might well be brought to the attention of the designer of relatively high-pressure apparatus.

Many transformers for power transmission are provided for adjustment of pressure with taps on the high-pressure winding for cutting out perhaps 10% to 15% of the winding. These

adjustment taps are usually either in whole or in part located on the outer coils nearest the line terminals. If the line terminals be connected to a pair of these taps, cutting out say 5% on either end of the coils, then the maximum pressure to ground within the transformer becomes 10% more than from either line wire to ground. This material increase of insulation strains is especially undesirable in high-pressure transformers, where small brush discharges become troublesome, not only in air-cooled but also in oil-cooled transformers. Moreover the outer turns near these taps must be heavily insulated from one another to withstand lightning and other static strains.

If all these taps be made on adjacent ends of coils nearest the middle of the total winding, then the internal pressure in the transformer never exceeds line pressure; lightning strains are confined to the outer ends of the end coils, and when the taps are connected to cut out, say 10% of the total turns, the effect is merely an electrical over-lapping of the turns which are cut out, and the latter, if of equal number on the two adjacent coils, might even be connected in parallel, saving, in this assumed case, 7.5% of the $I^2 R$ loss in the high-pressure winding.

As to bushings, glass is being rightfully tabooed; it is fragile and necessarily of too small a diameter, thus naturally carrying too dense a charge on its surface, as noted in the paper. The tube is a condenser, the entire bore being at the pressure of the wire, and some other pressure, usually ground, applied near the middle of the outside of the tube. Charging current flows to and from the ground, along the tube, held close to the smooth surface of the glass, thus breaking down a thin film of air. The thinness of the film may be illustrated by wrapping strips of tape around the tube, when, upon applying test-pressure, the breakdown discharge will pass between the glass and the tape.

The remedy is, first, to increase the thickness of the tube wall thus decreasing the capacity (which is also affected by the kind of dielectric employed) and at the same time increasing the surface along which the charging current will flow, thus in two ways decreasing the current density on the surface of the bushing; secondly, further to break up and dissipate the surface-charging current by insulating rings set approximately at right angles to the axis of the bushing, as suggested in the paper.

It is essential that the wall of the tube be so made as to avoid long, thin air spaces extending along the axis of the tube, as these will be the seat of local currents, which may lead to the failure of the whole bushing.

[For further discussion on this paper see page 276.]

MEETING AT CHICAGO, MARCH 29, 1904.

Discussion on "The Relative Fire-Risk of Oil- and Air-Blast Transformers."

James Lyman:—The following features should determine the selection of transformers, as well as other electric apparatus:

1. Reliability of service, including capacity for all probable overload conditions of practice.
2. Efficiency, regulation, the low rise in temperature under the various operating conditions.
3. Safety against personal danger to operators and safety against fire-risk, either from internal or external cause.
4. Compactness, simplicity of design, easy access to parts, and general cleanliness.

In small sizes the external surface of well-designed transformers is ample to radiate the heat due to copper and iron losses. The radiating surface per kilowatt, however, rapidly diminishes as the capacity increases, and in large sizes, from 1000 kw. up, it becomes absolutely necessary to carry off the heat by some circulating fluid, such as air, blown directly through the coils and the iron core, or water circulating in a coil of pipes suspended in the oil. While in transformers from 50 to 300-kw. capacity, it is perfectly practicable to design them of the self-cooling oil type, it is frequently more desirable to have them cooled from some entirely external source, such as by air-blast or water, as they can then be installed in a limited space where proper surface radiation cannot normally be obtained. The air-blast transformer has the advantage over the oil- or water-cooled type in being pretty nearly fire-proof. The insulation on the winding is the only combustible material in its construction, and this amount is comparatively small. Burn-outs in properly designed air-blast transformers are exceedingly rare, due to the fact that a comparatively low temperature can be maintained even under heavy overloads by varying the air-blast. The power required for driving the blowers is generally from 0.1 to 0.3% of the rating of the transformers, according to their sizes, so that the power required need not be considered in the efficiency of the transformers. In cases where burn-outs have occurred in air-blast transformers the writer does not know of an instance where the fire has extended beyond the damaged transformer, the shell of the air-blast transformer acting as a good fire-proof casing, and in case of external fire the air-blast transformer is seldom seriously damaged. When properly designed for thorough circulation of oil through the core and around the coils, and with properly-designed tanks, oil-cooled and water-cooled transformers should not offer serious fire-risks. The speaker believes that within the limiting pressure for which air-blast transformers can be used they are decidedly preferable to the oil

cooled. They are clean, compact, thoroughly reliable, and fully equal in efficiency and other characteristics, and, if anything, capable of greater overload abuse than the oil type. Above 30 000 volts the oil-cooled and water oil-cooled transformers must be used.

W. A. BLANCK:—In regard to the two types of transformers for transmission plants mentioned in Mr. Rice's paper, it is the speaker's opinion that a pressure of 30 000 volts forms the upper limit for the air-blast and the lower limit for the water-cooled oil transformer.

If the transformers be installed in the power-house and not separated from the engine-room by a fire-proof wall, the speaker is in favor of air-blast transformers on account of smaller first cost, convenience in securing proper attendance, and the considerably smaller fire-risk due to the small quantity of inflammable material.

If conditions call for a separate transformer house without special attendance, the speaker is in favor of water-cooled oil-immersed transformers set over suitable trenches so that any overflowing oil would be properly discharged outside of the building. The principal trouble encountered so far in oil transformers seems to arise from external sources, such as arcing switches and lightning-arresters mounted on wooden frames near the transformers. To overcome these fire-risks it will be necessary to use oil switches in brick compartments and to install all wiring on insulators carried by iron supports. Moreover the most essential requirement is to make the transformer house completely fire-proof.

If for any reason self-cooled oil transformers are installed, the cases, if made of corrugated iron, should be strong enough to withstand external heat and should also be set over a suitable trench to discharge any overflowing oil. A fireproof housing is also greatly to be desired.

P. JUNKERSFELD:—One advantage of the oil-cooled type would appear particularly in those instances where large currents are taken from transformers for synchronous converters, at comparatively low pressure. Connections of sufficient current carrying capacity for 1000 kw. at 160 volts, would be difficult to bring into the top of an oil-cooled transformer.

Under such circumstances the air-blast type would have the advantage of making possible a shorter and more satisfactory heavy copper connection between transformer and synchronous converter.

G. N. EASTMAN:—He asks if any one has ever seen an oil-cooled transformer burn up; that is, the oil actually take fire and burn.

D. W. ROPER:—A case of that kind occurred in the East some time ago. A large single-phase, low-pressure transformer had the two sides of the secondary circuit brought out through different holes in the iron case. The hysteresis loss

in the iron produced enough heat to start a flame at one end, but the transformer did not burn up. The circuit was opened and the blaze was smothered.

In another case at the same plant an oil-cooled transformer of an early type was cooled by means of a water coil, in a tank removed from the transformer. An electric arc in the chamber in which the transformer piping was located burnt a hole in the pipe, which led from the transformer to the oil-tank. There was no check-valve in the pipe, and the arc set fire to the oil. The blaze continued until all the oil in the tank was consumed. This took some time, and in the meantime the switchboard operator tried to pull switches in the endeavor to put out the arc. Long before the fire stopped every switch in the plant was open. Those are two cases where fire occurred without destruction to the transformers.

G. H. Lukes:—If a device for smothering a fire in air-blast transformers is desired, use might be made of carbonic acid gas, which is easy to obtain. In case of a fire in an air-blast transformer, the air could be shut off and the carbonic acid gas turned on, when the fire would be quickly put out.

Discussion on "Group-Switches in Large Power-Plants."

W. G. Carlton:—In laying out a distributing system for high-pressure work, simplicity should be aimed at in the switching arrangements at both the generating and receiving ends of the lines, and also in the way of avoiding taps on the lines as far as possible. If the system is of any size, conveniences for testing should be provided so that no unnecessary time will be lost in starting up the system after a shutdown, and also so that in case of trouble on a line the latter can be easily and quickly tested without interfering with the operation of the rest of the system and without danger to the persons making the test. This matter is frequently lost sight of in the design of a station, and the men who must operate it are placed at a disadvantage.

Oil-switches on high-pressure lines are commonly provided either with a straight overload tripping attachment, with an overload time-limit element or with no overload at all. If it is necessary to use any overload device, and it frequently is, it should have a time element depending on the load. To illustrate: if the normal maximum is 300 amperes, the overload should be set so that it would hold 450 amperes for three seconds, but would open instantly on 700 amperes. These figures are used for illustration and would vary with conditions.

The straight time-limit device is all right in case of an overload, but if this overload approaches short-circuit conditions, the switch will not open before the overload has dropped the pressure on the system sufficiently to cause synchronous apparatus to drop out of step. This has caused the abandonment

of straight time-element overload devices in the care of one station.

Underground high-pressure transmission lines should be carefully protected in manholes, both to provide against fire spreading from one cable to another and also to confine the arc in case a cable burns out. In the case of an unconfined arc if the system is of any size, excessive pressures are likely to be set up due to resonance, and the insulation of other cables and apparatus is likely to be broken down. Various forms of protection have been used. One of the best is split vitrified clay tile, using 45-degree elbows for the bends in the cable. When carefully installed, this gives practically a continuous conduit line through the manhole. On long lines the lead sheaths of transmission lines should be broken at suitable intervals to prevent the flow of stray currents.

P. JUNKERSFELD:—In connection with Mr. Stillwell's paper, he would like to emphasize the fact that it is difficult to discuss this problem without referring to a particular case. Mr.

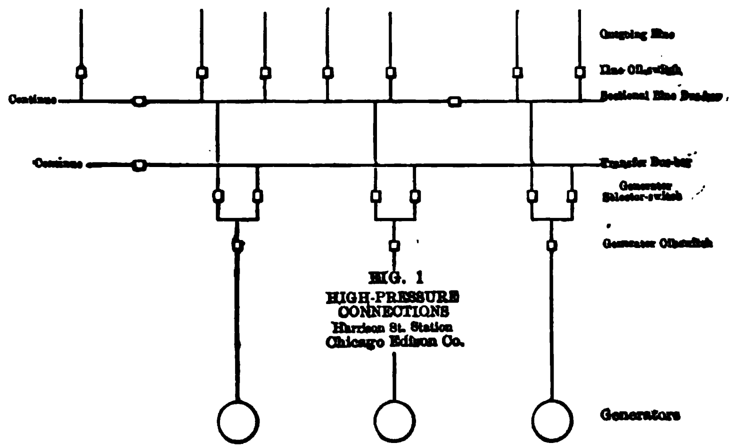


FIG. 1
HIGH-PRESSURE CONNECTIONS
Harrison St. Station
Chicago Edison Co.

Stillwell selected the case of a large power-house for street-railway systems. The conditions were known; that is, the load was pretty well known in advance, and the location of the sub-stations and the arrangement of the system could be figured out quite closely in advance. It was a conversion from steam to electric motors in the case of the Manhattan system and with the road in operation they could determine readily the load on transmission system. Likewise with the Metropolitan.

In a central-station system engaged in the lighting and power business for instance, the conditions are somewhat different. It is not only a problem of designing the switching apparatus for conditions as they then appear, but also of meeting the conditions that arise in a rapidly-growing system.

Due consideration must be given to the percentage of total investment involved in different parts of the system. For instance, an additional investment in switches would often be small compared to an additional investment in lines. Therefore, while the number of long lines and the number of generating units are comparatively few, it will very often pay to introduce more flexibility in oil-switches and bus-bars.

To illustrate, in one of the Chicago stations, which is developed to its ultimate capacity, the high-pressure switching apparatus was entirely rearranged and overhauled during this last year. In that case the problem was not difficult and somewhat similar to that cited by Mr. Stillwell. The solution, however, was slightly different. Instead of the group-switch arrangement, a sectionalized bus-bar scheme was used as shown in Fig. 1. This line bus-bar is sectionalized in such a way that each generator may be made to supply its own section independently if desired. The transfer bus-bar can be divided into two sections only. Each generator has two selector-switches by means of which it can be connected either to its

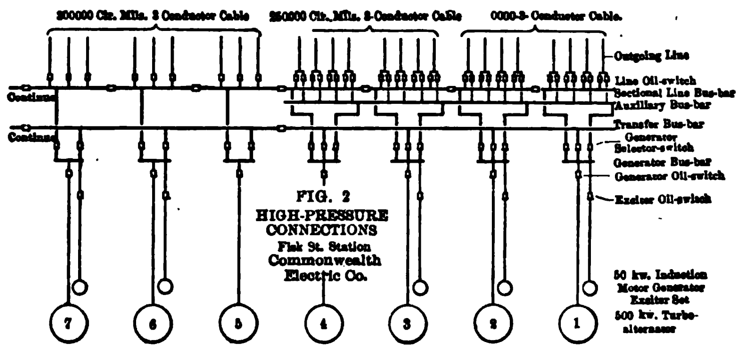


FIG. 2
HIGH-PRESSURE CONNECTIONS
Fisk St. Station
Commonwealth Electric Co.

own section of the line bus-bar or to the auxiliary bus-bar. With the generator-switch open and the two generator selector-switches closed, we also have a tie between a section of the line bus-bar and the auxiliary bus-bar. While each line has only one switch, there would, in case of trouble on line, always be two switches in series as the tie-switch would be used to cut off the section having trouble, in case the line-switch failed. This case is the Harrison Street Station of the Chicago Edison Company. The conditions were fairly well known when the overhauling was done, and the general design was, therefore, a comparatively simple matter.

In another case, the Fisk Street Station of the Commonwealth Electric Company, it was somewhat different. The scheme adopted is a little more complicated, at least it will be during the earlier development of the station. As the station grows larger, any one generator or line going out of service is a smaller percentage of the total and will not cripple

the system so seriously as in the first few years. The scheme is similar to the one previously outlined and shown in Fig. 1, except that there is an additional bus-bar introduced.

As shown in Fig. 2, there is a sectionalized line bus-bar, a transfer bus-bar and a third bus-bar known as an auxiliary bus-bar. In this case, there are three instead of two generator selector switches, and two instead of one line switch. One or more lines can be connected to the transfer bus-bar only through the medium of the generator selector switches, which under that condition perform the function of so-called group-switches. The installation of selector switches on each line and of the auxiliary bus-bar introduces a little more complication than the scheme shown previously, but the total number of switches is not greater than used in most high-pressure stations, having same size of generators and number of lines. Ultimately it is hoped to have simply the sectionalized line bus-bar and the one transfer bus-bar similar to the scheme shown in Fig. 1.

W. A. Blanck:—Mr. Carlton's remarks in regard to time-limit devices in connection with high-pressure oil switches are very interesting, but disappointing to learn that these devices in which so much hope has been placed for the satisfactory operation of a high-pressure distributing system have been discarded. Why has this been done?

W. G. Carlton:—In regard to the straight time-limit switch, a number of cases of trouble occurred, such as a short circuit on an underground line. If there is a time-limit switch on that line and the time limit is held on and will not allow the switch to open, the short circuit will work back and affect the whole bus-bar with which the line is connected, and, as a rule, will shut down everything running on that bus-bar. There have been a few cases of trouble on underground lines, not exactly in the nature of short circuits, possibly a ground, or something which would cause a good heavy overload and when the time limit has not been on, the switch has opened and cut out the line; when it has been, it has shut down everything on the bus-bar.

W. A. Blanck:—Could not that difficulty be overcome by the proper setting of the time-limit devices, for instance the feeder-switches for two seconds and the generator-switches for four or six seconds?

G. N. Eastman:—The trouble with setting the time-limit switch for any given predetermined time is increased by the size of the system and the manner in which the lines are run. Conditions will arise in almost any system where there will be time-limit devices on lines which normally are not in series but under conditions of short circuit will be fed in series. The result is that other circuits are interrupted which have time-limit devices on them and always will be interrupted unless on that circuit on which the short circuit occurs, the time limit is set so that it operates before all others. One

can readily conceive how impossible it will be in a large system to vary the time so that these different time-element devices would be caused to operate for the location at which there is a short circuit.

P. JUNKERSFELD:—It seems that the original time-limit device was developed when the high-pressure system on which it was used was comparatively small and had comparatively few lines or branches. As the systems grow much larger, particularly in the cases cited by Mr. Carlton and Mr. Eastman, the straight time-limit relay is satisfactory for overload, but it is unsatisfactory for serious trouble on cables. Before such a time limit operates a good many things happen and it is necessary to have a device which will open very quickly and positively.

W. G. CARLTON:—In the matter of the time limit, if the time is at all appreciable, before that time has elapsed with a heavy short circuit, unless there is a very large amount of power on the bus-bar, the pressure on that bus-bar will drop sufficiently so that synchronous apparatus will all be stopped. That is one of the serious objections to a time-limit device.

DISCUSSION ON "OIL-SWITCHES FOR HIGH PRESSURES."

W. A. BLANCK:—The superiority of oil switches over air-break switches for high-pressure work, in so far as it relates to reliability of operation and line disturbance, is very well recognized, but still there are many cases where the much-abused air circuit-breaker in the form of a fuse breaking under oil or a lead fuse in connection with a spring-operated lever is the only device suitable to be installed.

In the case of a high-pressure transmission line passing a mining district, where the customers are usually widely scattered over the territory, and sub-stations with static transformers of less than 100 kw. capacity are often required, it is evident that an automatic oil circuit-breaker in a brick compartment would involve nearly double the investment of the transformer.

But as a matter of fact the high-pressure tap to the transmission line will be interrupted only in case of a breakdown of the transformers, since all secondary shorts or overloads are limited by properly dimensioned secondary fuses, so that the action of the air circuit-breaker, installed in connection with a set of disconnecting switches, is only called for in utmost emergency.

JAMES LYMAN:—In most cases the source of current supply for operating oil switches is a storage-battery, and wherever it is used it has proved a very reliable source. It is very seldom that an automatically operated oil-switch fails.

P. JUNKERSFELD:—He believes that although switches are carefully built and located in the station, but little thought is given to the arrangement of the connections. This should not be the case.

DISCUSSION ON "TERMINALS AND BUSHINGS FOR HIGH-PRESSURE TRANSFORMERS."

W. G. CARLTON:—The speaker desired to know if any one present could state whether or not there are any 80 000-volt lines in operation.

E. O. SESSIONS:—In California the lines are operated from 45 000 to 60 000 volts, depending upon the reactance in the line.

P. JUNKERSFELD:—In a very large proportion of high-pressure work oil-switches play rather an important part. One question of importance is the building of suitable doors for oil-switches. The question has been discussed in different parts of the country as to what is the best and most satisfactory door for an oil-switch compartment. The glass door and wire glass door can readily be seen through for inspection purposes. While with the iron door or with the Alberene or slate slab you cannot readily inspect, and are liable to use the switch when it is not in order. Alberene slabs and iron doors can not be so easily and safely removed as glass ones and consequently the switches are not so frequently inspected as they should be.

G. N. EASTMAN:—One instance might be cited where a company operating in Chicago had a solid door and for some reason the oil suddenly disappeared from the oil wells. There was only a slight indication of this from the oil on the floor outside. The switch, however, operated satisfactorily on closing, but not so well on opening the circuit. When the doors were removed it was seen that there was considerable oil inside the switch.

W. G. CARLTON:—The speaker thinks the amount of wood in the frame of the door is not enough to cause much fire. There is practically an equal amount of inflammable material close to the switch in the insulation of the leads. In operating a number of lines on one bus-bar, when several switches open up due to trouble, it is not always possible to tell on which line the trouble is. If the oil-switch opens up a line on which there is a short circuit, some oil will generally be thrown from the switch. With a glass door the attendant can see where oil has been thrown out of the switch and thus save time in locating the trouble, as has been proved by experience in a number of cases. There is the possible objection of breaking the glass, but there is not much fire-risk with the amount of wood available.

I. E. BROOKE:—In the construction of some oil-switches it seems as if an iron door comes rather close to the live copper, and that the liability of grounding on the iron door would more than overbalance the objection to the fire element on a wooden door.

MR. THOMAS:—The speaker believes it has been the practice to ground the framework of the oil-switch as well as the door. He approves of it and considers that everything in the shape of framework on a switchboard should be grounded.

P. Junkersfeld:—One point particularly has been brought out in connection with oil-switches, and that is that they need a great deal of attention. A switch is looked upon as something which can be operated occasionally and then left alone; but that is not the case with an oil-switch. It must have frequent and good inspection, and in order to get good inspection it must be arranged so that the operator may easily see its condition. One of the speakers has made the suggestion to have an iron door which would open outward and downward. Why does he say you get better inspection when a man opens an iron door than when he looks through a glass door?

E. O. Sessions:—The speaker has used wooden doors with glass windows for the switch-cells, but they were replaced by iron doors, about eight and a half inches away from switch-tank with a two-inch air-space all around the door, on account of the destruction of the wooden ones.

P. Junkersfeld:—Glass doors of heavy plateg-lass in three sections, which will enable every part of the switch from the bottom terminal to be seen, have been in service for some time.

W. G. Carlton:—In the case Mr. Sessions mentioned of the glass door being blown off, why would not the same thing happen to an iron door? also trouble has been caused by switches grounding to an iron door.

E. O. Sessions:—With wooden doors the case was fitted tight, while about the iron doors there was left a two-inch space. With glass doors after one blowout of the switch, the glass would be so obscured that it would be impossible to note what happened without opening the door, but arranging the iron door so that it lacks two inches of closing will permit the inspection of the switch.

R. F. Schuchardt:—To illustrate the point brought out by Mr. Brooke, the speaker cited the following case: An oil-switch had opened on a very heavy overload and some of the porcelain posts were so badly broken that one of the oil-wells fell forward. After the switch was opened the lower part connected to the oil-wells was still alive and if this well had fallen against an iron door thoroughly grounded, the resultant short circuit would certainly have caused great damage. With a wooden door with a glass front no live parts could come in contact with metal.

E. O. Sessions:—In the Waterside Edison station in New York all the doors are made of soapstone, or Alberene, as it is called, and are fitted in close against the brickwork.

Edw. Schildhauer:—If Mr. Session's advice is followed to erect the door two inches from the brickwork, the fire-proof advantage of the iron door is *nil*. It would look rather odd to see a brick switch compartment lined with Alberene stone on three sides and equipped with an iron door on the fourth or front side, while the distance from the oil vessel to the door is the same as to the Alberene. If an oil vessel bursts with

enough generator capacity back of it, the speaker believes that there will be in most cases very little left of the iron door.

P. JUNKERSFELD:—The large companies in Chicago have had some oil-switches in operation for a number of years; in fact, some of the first hundred switches that were made for the Metropolitan station in New York, which was the first extensive installation of the compartment-type of switch, were shipped to Chicago. The first had the asbestos and iron doors, then followed Alberene doors, and more recently the advantages of the glass door appeared. One or two experiences brought out very forcibly that it was desirable to have a glass door and at the same time a fire-proof door. That, of course, meant a metal casing. After that, however, it was realized, as Mr. Carlton pointed out, that what little wood is introduced does not seriously diminish the fire-proof character of the door and does not increase the danger. The fire-proof barriers between the phases are really depended upon to prevent trouble. It is not often that the switches are gotten close enough so that anything thrown out at the front would be a serious matter.

G. N. EASTMAN:—Some five years ago, when the question first came up about using oil-switches in preference to air-switches, he made some tests to determine what the relative rise in pressure in the cable would be upon opening the circuit. He found that in a three conductor No. 00 cable three miles in length, the changing current was great enough so that upon opening the circuit with an air-switch, the arc could be gradually drawn up, and an increase in pressure of 50% "noted by a static voltmeter" could be obtained. If the switch was opened quickly, using a single break in the oil, no increase in pressure could be noted. Drawing the arc out in the oil a rise of from 10 to 15% was obtained. By connecting four breaks in series in oil it was practically impossible, under any conditions, to obtain a rise in pressure.

The speaker believes that upon opening a short circuit the tendency of the arc to hold would be reduced by having breaks in series. With some conditions, it is only by holding the arc—"the arc acting as an interrupter"—that you obtain a rise in pressure. The rise will be more severe with a short circuit under certain conditions than with only the charging current.

MEETING AT PITTSBURG, APRIL 7, 1904.

DISCUSSION ON "THE RELATIVE FIRE-RISKS OF OIL- AND AIR-BLAST TRANSFORMERS."

J. W. FARLEY:—For fires inside of transformers themselves, a chemical extinguisher can be used to good advantage. If a flash should occur inside the transformer, and ignite the oil which has soaked up on the insulation on the leads, the fire can be put out with ease by means of an extinguisher, which will be very effective even if the surface of the oil is actually burning.

Light brick walls may be built between the different transformers and low deflecting walls may also be arranged so that in the event of an accident to the transformer case, due perhaps to the falling of a beam or tile from the roof at the time of a fire, the escaping oil would be prevented from spreading over the premises and would be diverted either into a sewer or out of the building at some point where it would do the least damage. It is always a good plan to pipe from the transformer cases to a storage-tank or to a pit or sink-hole located in the most advantageous place, in order that in time of emergency the oil may be withdrawn from the transformers.

One field for the air-switch is its use for high pressures, where the amount of power is not very great. Under these conditions the air-switch will act just as satisfactorily as an oil-switch and often is very much cheaper than the latter. This is particularly true for pressures between 20 000 and 40 000 volts, and where the amount of power available on short circuit is comparatively small, as at the end of a transmission line at a sub-station with an output of 600 or 800-kw. Air-switches can easily be installed and at a cost probably not one half that of installing oil-switches.

Regarding the relative amount of space required by air-switches and oil-switches, in a complete layout for a typical transformer station for a single-phase railway plant it was found that the use of air-switches made just as compact, if not a more compact, plant than could be secured with the oil-switches, as the latter needed disconnecting switches and series transformers for their operation.

N. J. NEALL:—The speaker has noticed that in the West so much more account is taken of the ability of electrical apparatus as to afford continuous service than of its efficiency. One instance of what is now considered an old station has the high-pressure transformers in the main power-house only a slight distance from the generator. During an accident to the switching apparatus considerable burning oil was thrown out on the floor of the power-house; this heated up the transformer cases but did not injure the transformers.

Another plant visited had placed each transformer in a complete building by itself, the idea being that if one transformer

went out it would not communicate fire to the adjacent transformers.

A. B. BOND:—There is one point in connection with air-break switches which has not been brought out to-night and that is the question of thoroughly drying out the switch before its installation. Conditions sometimes arise under which the wooden parts of the conventional fuse-switch may become damp and thus introduce an element of danger to the attendants.

In a prominent Western plant considerable trouble was experienced with fires in the oil-filled transformers. The cases were perforated at the top, and it was found that by thoroughly caulking up all openings, the trouble from fire was eliminated. In this plant it was customary to use sand for fires in transformers. A patent extinguisher was also employed in which the novel feature of an interrupted stream was incorporated. With this extinguisher it was impossible for an attendant to receive a serious shock in consequence of directing the stream on live high-pressure wiring—a danger that exists where a continuous stream is used.

DISCUSSION ON "THE USE OF GROUP-SWITCHES IN LARGE POWER-PLANTS."

B. P. ROWE:—It appears that the use or disuse of group-switches is one which will be mainly decided from the station operator's standpoint. The fact that the Metropolitan Street Railway Company in their 96th Street and Kingsbridge stations and the Manhattan Railway Company in its 74th Street station are both in favor of using group-switches seems to indicate that there must be enough good reasons for using the system to overbalance the objections Mr. Stillwell mentions, and any others he has not mentioned. The speaker has noticed that other large stations beside those of the Metropolitan and Manhattan companies are being laid out with group-switches, and for large stations of this class, with a large number of feeders, there seems to be a decided sentiment in favor of using this type of switch.

In the first place, if a power station is a large one no one questions the advisability of using two sets of bus-bars. If every feeder must be capable of being thrown to either of the two sets of bus-bars, there are required three oil-switches to each feeder. If the feeders are grouped as Mr. Stillwell has described, the two switches which act as selector-switches for one feeder will, if large enough, be suitable to transfer a whole group of feeders; so that with a double-throw system, the group-switches, acting as selector-switches, are rather a saving in apparatus than otherwise.

But when a single set of bus-bars is used, with the ring system

and junction-switches, the group-switch is undoubtedly an extra to be considered, just as Mr. Stillwell has considered it. Such a case as this is the Kingsbridge power-station, where the group-switches were installed by the Metropolitan Street Railway Company, who already had had the experience of operating the 96th Street station to guide them, and considered them necessary.

Under such conditions, an arrangement of feeders is made, so that the opening of a group circuit-breaker does not shut down an entire sub-station. Mr. Stillwell presents a diagram which indicates that if the operator suddenly opens a group-switch in an emergency, to cut out a bank of six feeders, he thereby shuts down an entire sub-station. The arrangement the writer has in mind is to have one or two feeders from a group carried to one sub-station and the balance distributed to other sub-stations, so that each sub-station draws its supply of current through two or more group-switches. Thus the liability of shutting down sub-stations is not so great. The writer understands that the Kingsbridge and 96th Street feeders are connected in this way.

A point not brought out by Mr. Stillwell is that when a group-breaker is installed it must have a capacity sufficient to carry all of the feeders in the group and to open the total load under the worst conditions. Now if the feeders in the group are carrying large amounts of energy it is manifestly a more difficult thing to open it all on one switch than to divide the load and open it instead on the several feeder switches. In some cases it means a large switch and the amount of energy to be handled introduces an element which can hardly be neglected. There is obviously more liability that the large switch will cause trouble than any one of the smaller ones. In such a case a station operator would probably rather consider the group-switch an emergency-switch than to be habitually breaking large amounts of current on it to save time in transferring feeders or cutting them out of circuit.

This would seem to indicate that where feeders are of very heavy capacity so as to require large group-switches, they might be a source of trouble rather than a benefit unless they are reliable. Reliability is demanded because the group-switches are connected directly to the bus-bars. In the Kingsbridge power-station the opening of the group-switch automatically opens all the feeder-switches connected to it. This insures that there shall be two breaks in the circuit and might help out the group-switch.

A paper presented at the 188th Meeting of the American Institute of Electrical Engineers, Chicago, June 21-22, 1904.

PROTECTION OF CABLES FROM ARCS DUE TO THE FAILURE OF ADJACENT CABLES.

BY W. G. CARLTON.

The matter of the protection of cables depends largely on the number of cables and amount of room available. This protection is needed in stations and sub-stations, also in manholes on underground work; on inside work there is generally available room for separating the cables, and for this reason it is easier to take care of them than in underground work. In general, similar protection can be used in either place, except that in underground work material must be used which will not be affected by water, as manholes are liable to be flooded. Protection of cables in manholes will be considered particularly.

In old conduit systems where a large number of ducts have been installed and no attempt made at separating them as they enter manholes, it is a difficult matter to protect cables. If, however, the work has been carefully laid out, plenty of room taken in manholes and the ducts spread so that there is a vertical space of from 8 to 12 inches between the two halves of the conduit line, it is much easier to ensure satisfactory protection. It should be borne in mind that a conduit line of a large number of ducts is not a desirable thing. Two independent lines will cost considerably more than a single line of the same capacity, but this extra cost is an insurance against future trouble.

On account of the large amount of energy carried by high-pressure cables their protection is of the utmost importance. High-pressure transmission cables operate usually at from 5000 to 15 000 volts and are nearly always three-conductor cables. It is to the protection of such cables that this paper refers particularly, although it will generally be found that protection

is needed more from burn-outs on low-pressure cables than from those on high-pressure ones. High-pressure cables are usually protected by automatic overload devices and, if these are satisfactory they will disconnect the cable before any large amount of damage is done. On the other hand, low-pressure cables may continue to burn without drawing enough current to cause them to be cut off. Cables generally break down in manholes due to poor work in jointing or to careless handling during installation. Various methods are in use for fireproofing and isolating them from one another.

A method employed in a number of places is to wrap the cables with asbestos paper or tape about 1/8 in. thick, using two layers and binding the asbestos on by means of steel or brass tape. The metal tape is wrapped either in an open spiral leaving an inch or more between turns, or with the edges touching leaving no open space. With the metal tape wrapped close there is less danger of the asbestos disintegrating on account of water in manholes or of other causes. The asbestos wrapping should be carried well into the duct. This protection has been found adequate by several large companies. Its life, however, is uncertain, particularly on underground work. One disadvantage is that in the case of loaded cables the heat is less easily radiated on account of the asbestos covering. Asbestos paper soaked in silicate of soda has been used for wrapping cables; this has the advantage of not requiring any metal tape for a binder, as the paper treated in this manner is cemented to the cable. It is doubtful if the silicate of soda treatment will be satisfactory for use in manholes that are likely to be flooded, although it should be in dry places.

A second method of isolating and protecting cables consists in providing separate chases or runways for them. Sometimes this is done by building special long and thin bricks into the wall of the manhole leaving them projecting so as to form a shelf. Soapstone slabs are also laid in the wall forming shelves or boxes for the cables. The cables may be further protected with asbestos if desired. It is difficult with this method of protection to make a satisfactory job where the cables enter the ducts unless there has been a very elaborate spreading of the ducts.

The third method of protection, which is very satisfactory when the cables run fairly straight through the manholes, consists of a covering of vitrified-clay tile. Ordinary single-duct

clay tile in 18 in. lengths is used, the tile being cut nearly through before baking so that it is easily broken in halves. The tile on the lower layer of cables is supported by means of light galvanized angle-irons run longitudinally through the manholes. The upper layers are supported on the lower ones. For the bends in the cables 45 degree curves with a 12 in. radius are used. These curves being laid in reverse similar to the letter "S" near the end of the manholes where the cable enters the duct. The tiles are laid in cement mortar forming a good mechanical piece of work and giving practically a conduit line through the manhole. One or two of the lower ducts should be left open at each end of the manhole for a space of about one-half inch so that water will drain from the conduit line. The principal objection to the use of tiling is, that in the case of trouble, making it necessary to remove a cable, the tiling must be broken out. Iron brackets are avoided by the use of tiling and there is no chance for current to flow from the lead sheath of one cable to that of another except such leakage as may occur due to moisture in the ducts. Personally, the writer is in favor of using the split-clay tile covering where possible, and asbestos paper and brass tape in other places.

High-pressure cables should be covered, not only to protect them from the failure of adjacent cables but also on account of the dangers which may arise from an unconfined arc. Oscillations may be set up which will produce pressures many times in excess of that at which the cable is working, and these high-pressures are liable to break down the insulation on the cables or on the switchboard apparatus, transformers, or generators, which may be connected to the cables. For this reason one large company in New York has installed on all cables within a mile of the power-house, in addition to the regular asbestos covering, a sheet-iron armor 1/16 in. thick. This armor being rolled and especially prepared to meet curves or bends in the cable, each section lapping the next one. This sheet-iron is clamped together so as to make a strong mechanical covering.

A manhole fire causes more trouble at the top of the hole than lower down, and for this reason the most important cables should be kept towards the bottom of the manhole. In the case of large manholes it will often be found desirable to build a partition wall longitudinally through the hole, making practically two manholes.

While burn-outs in cables are bound to occur—and for this

reason, fireproofing cables, particularly important ones, is necessary—at the same time, the number of burn-outs can be kept to a minimum by careful work. Only experienced and careful men should be allowed to train cables. The manhole should be built so that it is not necessary, or even possible, to make a short bend in the cable in taking it from the duct to the side of the hole. The jointing should be done by thoroughly reliable men and they should be given to understand that it is not speed which is wanted but first-class work. If it is not desirable to do the jointing as soon as the cables are pulled in, the ends should be sealed, first cutting them back far enough to be positive that there is no moisture present. Tests for moisture should be made if there is any reason to suspect its presence.

The experience of one company in Chicago has been that nearly all trouble that has occurred on three-conductor high-pressure cables has been due to defective joints, to moisture in the cables near the joints, or to sharp bends in the cable. Some burn-outs have occurred due to the lead sheathing of the cables being damaged by electrolysis. This can be prevented by grounding the lead of the cables at suitable intervals or by insulating them if possible. Frequent inspection should be made to determine whether the lead sheaths of the cables are carrying current, a recording voltmeter having a total range of from three to five volts will be found convenient for this work and a chart covering the entire day will be found much more valuable than a few single readings.

DISCUSSION ON "PROTECTION OF CABLES FROM ARCS DUE TO FAILURE OF ADJACENT CABLES."

RALPH D. MERSHON: In addition to the protection of cables in manholes, there is also the question of the protection of cables in power-stations. It is not always easy to install cables in such a way that they will be protected from each other, especially if the power-house has not been laid out with reference to them. The question of protecting cables by means of asbestos and similar wrappings has for its chief objection that there is no chance to get rid of the heat in the cable. For that reason, and for the greater one of reliability, the speaker very much prefers either tile or brick protection to asbestos.

Mr. Carlton speaks of using a voltmeter for determining the current being carried by the cable sheath. Will Mr. Carlton please explain a little more fully the method of using the voltmeter, and also the method he prefers for permanent grounding of metal sheaths?

W. F. WELLS: Mr. Carlton refers to two independent lines of subway as being an insurance against trouble on a high-pressure cable system. In New York this practice has been carried a little further, and four separate and independent trunk subways have been installed, leading from the generating station along four different routes. From these trunk subways run branches arranged so as to give each substation two or more feeders, following entirely different subway routes. In case of a manhole caving in, or general trouble on any subway line, not more than one quarter of the high-pressure cable system can be affected.

Regarding the injury to high-pressure cables by the burning out of low-pressure cables; this has occurred, but burn-outs have also originated in the high-pressure cables. Some of these troubles were due to defective joints and some to short bends in the cable where it leaves the duct. In order to obviate this latter cause, the cable is now run straight out of the duct 12 in. before bending it over to the side of the manhole, thus preventing the edge of the duct from cutting into the sheath of the cable.

For the past two or three years the high-pressure cables in manholes have been wrapped with asbestos bound on by galvanized-steel tape, as described by Mr. Carlton, and the results have been very satisfactory. No trouble has been experienced from the heating of the cables where covered with this asbestos wrapping. In the stations, clay ducts or iron pipes are used wherever possible to protect the lead-covered cables, and, when there is sufficient space, braided cables are carried on insulators through runways of brick 12-in. square.

H. C. WIRT: Will Mr. Carlton state whether he considers an underground line more reliable than overhead line as regards interruption of service?

RALPH D. MERSHON: Mr. Carlton speaks of the extra ex-

pense of separating ducts. It seems that in some cases separation may not in the end be an extra expense. The capacity of the subway is not necessarily proportionate to the number of ducts in it. Allow a certain limiting value to the temperature of the cable, then the ducts near the center of the conduit will not be as effective as those outside, no matter how they are arranged; if they are separated, it might be cheaper in the end because of the greater capacity the two subways would have over the single. So far as the speaker knows there are no accurate data in regard to this matter. The speaker has done a little work himself in special cases, and some work was done at Niagara some time ago. Perhaps Mr. Carlton and Mr. Wells have some information on this subject.

W. G. Carlton: In regard to the capacity of the cable being lessened in a larger conduit line; the speaker has no accurate information on that subject. Where cables are run at extremely heavy loads the gas generated inside of the cable will puncture the lead sheath, and this is one of the limiting features. The permissible watt consumption per linear foot of cable depends on the number of cables in one conduit line. With a single cable 20 watts per foot would probably be safe; with a larger number of cables, three or four might be the limit.

It is a good plan to treat the cables in the power-house—if they are lead-covered ones—practically the same as you would for underground construction. A conduit line can either be built, or when the cables are in place they can be covered with split clay tile. The ends of the cables need special care. Three-conductor cables must have some sort of terminal bell which allows spreading out the conductors for connection to the single-conductor cable, this bell to be filled with an insulating compound.

In regard to detecting possible stray currents on the lead sheaths of cables; a Bristol recording meter with a five-volt scale has been used; this is fairly satisfactory. A meter with the zero line in the middle of the chart and giving readings each side of this line would be much better. The voltmeter is connected between the lead sheath of the cable and a good ground. In our stations we connect with the ground plate; we have a ground bus-bar in our stations connected to several ground plates. In a manhole it would be connected to a water-pipe or sometimes to the cast-iron frame of the manhole or to a rod driven in the ground. The grounding of the cable sheaths is done ordinarily in the power-house, on the brass bell on the end of the cable.

Answering Mr. Wirt's question in regard to overhead and underground lines; in the case of one company operating possibly 75 miles of 9000-volt lines, 65 of which is underground, possibly 90% of the trouble on the lines is on the 10 miles of overhead line. This has been caused generally by boys throwing wires over the line, or by kite-strings.

H. B. ALVERSON: When the asbestos covering a cable is saturated with silicate of soda, the wrapping will harden and become nearly as good a conductor of heat as the lead jacket; this overcomes the objection that asbestos covering confines the heat within the cable.

W. G. CARLTON: How does that stand in a wet manhole?

H. B. ALVERSON: We have had no experience of that sort.

E. M. LAKE (by letter): In visiting some of the larger Eastern stations, about three years ago, it was observed that very little attention had been given at that time to the protection of outgoing cables. The bus-bars and immediate connections were protected by a most elaborate scheme of barriers built up of brick and concrete and of soapstone. The outgoing feeder lines, however, and in one or two places the main leads from the generators, were laid side by side upon cast-iron racks or upon thin sheet-steel shelves.

When this question came up in connection with the design

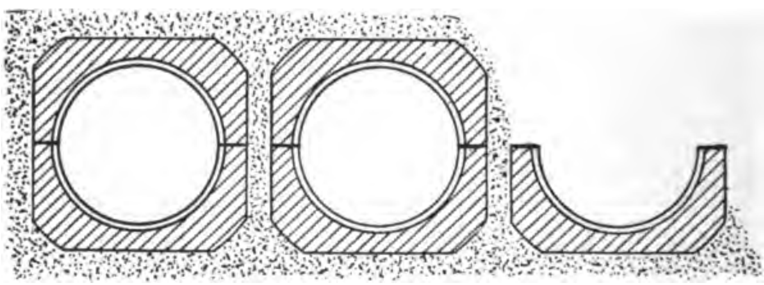


FIG. 1.

of certain Chicago sub-stations several methods were considered for protecting and isolating the whole cable equipment so as to reduce to a minimum the liability that a burn-out would spread to adjacent cables. The plan of using thin slabs of slate or vitrified clay was not found feasible because of the difficulty of applying in places where the structural work and cables were already in place. Then, too, this plan did not afford a simple and ready method of completely enclosing the cables where there were several in one run. Steel shelving and partitions when used alone were open to the same objections, besides being still further objectionable on account of the very small resisting power when subjected to the intense heat of an electrical burn-out. The proposition then narrowed down to some form of vitrified clay conduit because of the convenience of form, good mechanical strength, and high arc-resisting powers. Since the application must very often be made to cables in place, a split or divided form was necessary. There were found two forms of split conduit. One was divided in a straight line upon the diameter of the bore (Fig. 1). The other

was divided at an angle to the diameter, the two parts not being symmetrical (Fig. 2). These conduits were each applicable to certain conditions and locations, but a form was desired that would adapt itself readily to any and all places where protection of this kind was required. The style designed for this purpose was divided on lines parallel to the diameter of the bore but offset about an inch with reference to the diam-

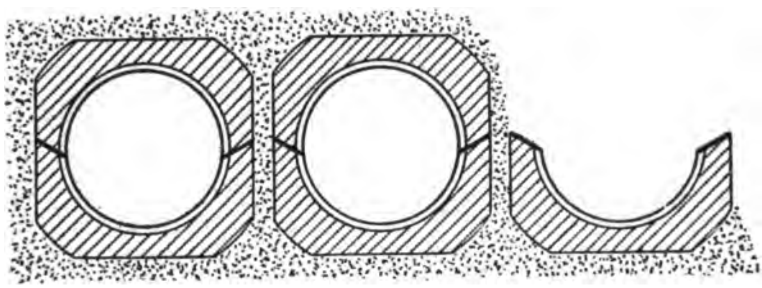


FIG. 2.

eter (Fig. 3). This gave two symmetrical sections which were interchangeable and possessed several distinct advantages over the existing forms.

It will be observed that in this form of conduit the joints in two adjacent ducts are not directly opposite. This of course insures a much more effective barrier between the cables enclosed by the conduit. For horizontal runs in walls the form

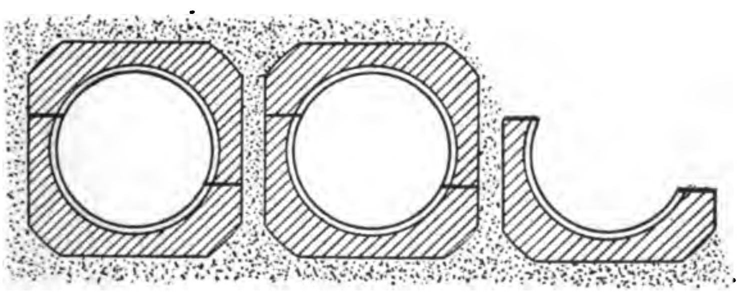


FIG. 3.

of the half-section is such that when laid it forms a convenient bed for the cable. Then when the cable is in place it does not form an obstruction to the laying of the remaining half of the conduit. Elbows on a safe radius for large cables and in an arc of 45 degrees were provided. Short straight lengths of 4½ in. and 9 in. were also ordered. With these forms and the standard 18-in. lengths it was comparatively easy to follow

the curves of any run of cables in a station or manhole, provided the cables had not been laid on less than a 12-in. radius.

A. M. HUNT (by letter): A covering for leaded cables where exposed in manholes can be made as follows: mix a stiff mortar using calcined magnesite (finely ground) and a saturated solution of magnesium chlorid; this combination hardens to stone in a few hours, and is heat-resistant and water-proof. Coat the lead of cable with oil, and wind it spirally with strips of canvas, putting the mortar on the inside of strip as the winding progresses. Any thickness of coating may be built up in this way. An outside finish of the mortar should be used. If the lead is not oiled, the mortar will adhere to it strongly, and be difficult to remove. The materials can be bought at prices which do not make the cost of such work heavy, and the covering is solid and effective.

As a protection against electrolytic action on the lead sheath of cables in an extensive network, the writer has tried operating a direct-current machine of low pressure with the negative terminal solidly connected to the lead sheathing and the positive strongly bonded to rails. The sphere of influence of this machine was much more extensive than might be imagined, and the application is worthy of consideration in cases where electrolytic action is severe. In the case noted the energy consumed was quite small.

J. W. F. BLIZARD (by letter): The writer suggests wrapping the cable in manholes with tape or thin asbestos, and then spreading a layer of about one-eighth inch of litharge on the cable. This will harden quickly and form a perfect protection from arcs, and may with ease be extended into the ducts for an inch or two. Ground mica and varnish would probably prove equally satisfactory, and cost considerably less. The asbestos or tape covering would prevent the compound used from adhering to the cable sheath, thus making the cable accessible in case of trouble, by simply breaking the protecting shell.

In addition to the dangers arising from the unconfined arc mentioned by Mr. Carlton, there is the often very serious one of gas explosions. No good ventilating system for underground conduits having yet been devised, this danger is an ever present one, and its importance should not be underrated.

A paper presented at the 188th Meeting of the American Institute of Electrical Engineers, Chicago, June 21-22, 1904.

SYNCHRONOUS MOTORS FOR REGULATION OF POWER-FACTOR AND LINE PRESSURE.

BY B. G. LAMME

General Discussion.

It is well known that the synchronous motor, running without load on an alternating-current circuit, for instance, can have its armature current varied by varying its field strength. A certain adjustment of field strength will give a minimum armature current. Either stronger or weaker fields will give increased current. These increased currents are to a great extent wattless. If the field is weaker than the normal (*i.e.* the field for minimum armature current), the increased armature current is leading with respect to the e.m.f. waves in the motor and lagging with respect to the line e.m.f. The current in the motor is therefore corrective in its nature. For stronger than the normal field, the current is to a great extent lagging and tends to lessen the flux in the motor and the current is leading with respect to the line e.m.f. A synchronous motor therefore has an inherent tendency to correct conditions set up by improper adjustment of its field strength. The correcting current in the motor is drawn from the supply system and this current also has a correcting effect on the supply system, tending to produce equalization between generated pressures in the motor and the supply pressure. This characteristic of the synchronous motor can readily be utilized for two purposes; namely, for varying the amount of leading or lagging current in a system for producing changes in the power-factor of the system (including transmission line, transformers, and generators), or a synchronous motor can be utilized for pressure regulation in a system.

As the synchronous motor can be made to impress a leading current upon the system, and as the amount of this leading current will depend upon the field adjustment of the synchronous motor, it is evident that this property can be used for neutralizing the effects of lagging current due to other apparatus on the system. The resultant leading or lagging current can be varied and the power-factor of the system can be controlled over a fairly wide range, depending upon the location of the synchronous motor or motors and upon the current capacity of the motor, etc.

As the wattless current in the motor is primarily a corrective current, it is evident that for most effective purposes for adjusting power-factor on the system the corrective action of this current on the motor itself should not be too great. When used for such purpose the synchronous motor should therefore be one which would give a comparatively large current if short-circuited as a generator. Also the motor should preferably be one in which the magnetic circuit is not highly saturated, for in the saturated machine the limits of adjustment in the field strength are rather narrow.

As has been noted above, if the field strength of the motor be varied, a leading or lagging current can be made to flow in its armature circuit, this current being one which tends to adjust the pressure of the armature and that of the supply system. It is evident that if the armature pressure is held constant and the supply pressure varied, a leading or lagging current would also flow. If for instance the line pressure were dropped below that of the motor, then a lagging current would flow in the motor tending to weaken its field, and a leading current would flow in the line, tending to raise the pressure on the line. If the line pressure should be higher than that generated by the synchronous motor, then the current in the motor would be leading, tending to raise its pressure; while it would be lagging with respect to the line, tending to lower its pressure. The resultant effect would be to equalize the pressures of the line and motor, and there would thus be a tendency to regulate the line pressure to a more nearly constant value. It is evident that the less the synchronous motor is affected by the corrective current and the more sensitive the line is to such corrective action, the greater the tendency will be toward constant pressure on the line. It is therefore evident that the synchronous motor which gives the largest current on short circuit as a generator would be the one which gives the greatest corrective action as regards pressure regulation of the system.

For such regulation, the synchronous motor which gives a comparatively large leading or lagging current with small change to the pressure of the system is the most suitable one. Or, the motor which gives the greatest change in the leading or lagging current is the one which gives best regulation. It is the change in the amount of wattless current which produces the regulation. This current could vary from zero to 100 leading, for example, or could change from 50 leading to 50 lagging, or could change from 100 lagging to zero lagging. Any of these conditions could produce the desired regulating tendency, but all would not be equally good as regards the synchronous motor capacity. If in addition to the regulating tendency it is desired to correct for lower power-factor due to other apparatus on the circuit, it would probably be advisable to run a comparatively large leading current on the line due to the synchronous motor, and the regulating tendency would be in the variations in the amount of leading current, and not from leading to lagging, or *vice versa*. A larger synchronous motor for the same regulating range would be required than if the motor were used for pressure regulation alone. It is evident that the current capacity of a motor regulating from 50 leading to 50 lagging need be much less than for current regulating from 100 leading to zero. It is evident therefore that if there is to be compensation for power-factor as well as regulation of pressure, that additional normal current capacity is required.

Regulating Characteristics as Fixed by Speed, Frequency, Etc.

In case such synchronous motors are required for regulation purely, it may be suggested that such machines be operated at very high speeds compared with ordinary practice. At first glance it would appear that such a synchronous motor could be operated at the highest speed that mechanical conditions would allow, but there are other conditions than mechanical ones which enter into this problem. For instance, it is now possible to build machines of relatively large capacity for two poles for 60-cycle circuits, and for very large capacities—say 1500 kilowatts—having four poles. Therefore mechanical conditions permit the high speeds, and the electrical conditions should be looked into carefully to see whether they are suitable for such service. As such synchronous motors should give relatively large currents on short circuit the effect of high speeds and a small number of poles on short-circuit current should be considered.

In order to give full-load current on short circuit, the field ampere-turns of such a machine should be practically equal to the armature ampere-turns, taking the distribution of windings etc., into account. By armature turns in this case is not meant the ampere wires on the armature, but the magnetizing effect due to these wires. Therefore to give, for instance, five or six times full-load current on short circuit, the field ampere-turns should be relatively high compared with the armature. This means that the field ampere-turns per pole should be very high, or the armature ampere-turns per pole very low. Experience shows that for very high speed machines, such as used for turbo-generators, there is considerable difficulty in finding room for a large number of field ampere-turns, and therefore in such machines it is necessary to reduce the armature ampere-turns very considerably for good inherent regulating characteristics. This in turn means rather massive construction, as the magnetic circuit in both the armature and field must have comparatively large section and the inductions must be rather high. This in turn means high iron losses in a relatively small amount of material compared with an ordinary low-speed machine, and abnormal designs are required for ventilation, etc., and for mechanical strength.

An increase in the number of poles usually allows increased number of field ampere-turns without a proportionate increase in the number of armature ampere-turns. This condition is true until a large number of poles is obtained, when the leakage between poles may become so high that the effective induction per pole is decreased so that there is no further gain by increasing the number of poles, unless the machine is made of abnormal dimensions as regards diameter, etc. Experience has indicated that in the case of very high-speed and very low-speed alternators, it is more difficult to obtain a large current on short circuit than with machines with an intermediate number of poles. For example, it is rather difficult to make a 600 kilovolt-ampere, 3600 rev. per min., two-pole machine which will give three times full-load current on short circuit. A 4-pole, 1800 rev. per min. machine can more easily be made to give three times full-load current on short circuit and with comparatively small additional weight of material. The material in the rotating part of the four-pole machine, while of greater weight, may be of considerably lower cost per pound. The stationary part of the four-pole machine may have a somewhat larger internal diameter, but the radial depth of sheet-steel will be less

than in a two-pole machine. The total weight of material in the armature of a four-pole machine may be practically no greater than in a two-pole machine. Therefore a two-pole machine of this capacity should cost more than a four-pole machine, if designed to give the same current on short circuit. A six-pole machine would show possibly a slight gain over the one with four poles, but not nearly as much as the four-pole machine would over the one with two poles. The real gain of the six-pole over the four-pole construction would be in obtaining a machine which would give more than three times full-load current on short circuit. It would possibly be as easy to obtain four times full load current on short circuit with a six-pole machine as to obtain three times full load current on four-pole machine. An eight-pole machine would be in the same way somewhat better than the six-pole machine. Therefore if a 600 kilovolt-ampere machine giving six times full-load current on short circuit is desired, it would be advantageous to make the machine with possibly eight to twelve poles. The question of which would be the cheaper would depend upon a number of features in design.

If very large short-circuit currents are desired, then, as indicated above, the number of poles for a given capacity should be increased, or the normal rating of the high-speed machine should be decreased. If, for example, the 600 kilovolt-ampere, 3600 rev. per min. machine, mentioned above, should be rated at 200 kilovolt-amperes, then it could give nine times full-load current on short circuit; but such a method of rating is merely dodging the question.

In general, the following approximate limits for speeds and short circuit currents for 60-cycle apparatus can be given. These limits are necessarily arbitrary, and are intended to represent machines which could probably be made without using too abnormal dimensions;

600 kilovolt-amperes, 3600 rev. per min., two to three times full-load current on short circuit.

1000 kilovolt-amperes, 1800 rev. per min., three to four times full-load current on short circuit.

1500 kilovolt-amperes, 1200 rev. per min., four to five times full-load current on short circuit.

2500 kilovolt-amperes, 900 rev. per min., four to five times full-load current on short circuit.

For 25 cycles it is more difficult to give limiting conditions,

as the choice of speeds is very narrow. If, for example, a 1500 kilovolt-ampere, 2-pole, 1500 rev. per min. machine can be made to give three times full-load current on short circuit, then as machines of smaller rating cannot run at higher speed, the limiting condition of such machines must be the amount of current which they will give on short circuit. In the same way a 4-pole machine running at 750 rev. per min. may be made for 5000 kilovolt-amperes for three times full-load current as the limiting rating, and there is no choice of speeds for ratings between 1500 kilovolt-amperes and 5000 kilovolt-amperes.

It should be noted that the above speeds are very high compared with ordinary alternator practice and are up to high-speed turbo-generator practice, but machines with the above short-circuit ratings and speeds are probably more costly to build than machines of corresponding ratings at somewhat lower speeds. It will probably be found therefore that for the above maximum current on short circuit the cheapest synchronous motors for the given ratings will have somewhat lower speeds than those indicated above. It is certain that the lower-speed machines will be easier to design and will be slightly quieter in operation. Probably best all-round conditions will be found at about half the above speeds.

The above limiting conditions are given as only approximate and are based upon machines having ventiliation as is usually found on rotating-field generators for high speed. Artificial cooling, such as obtained with an air-blast or blowers, could modify the above figures somewhat; but in general it has been found that high-speed alternators can be worked up to the limit imposed by saturation before the limit imposed by temperature is attained. Therefore if higher saturation is not permissible, then there may be relatively small gain by using artificial cooling.

Synchronous Motors on Long Transmission Lines.

One of the principal applications of such regulating synchronous motors would be for controlling or regulating the pressure at the end of a long transmission line for maintaining constant pressure at the end of the line, independent of fluctuations of load or change of power-factor. In this case, increased output of the transmission line may more than compensate for the cost of the regulating synchronous motor. In such a case the synchronous motor not only acts as a regulator on the system but costs nothing in the end. In general, the more current that such a synchronous motor will give on short-

circuit, the better suited it will be for its purpose at the end of a long transmission line.

Where a number of such synchronous motors are installed in the same station, the field adjustment must be rather carefully made, to avoid cross-currents between machines; and the saturation characteristics of the various machines should be very similar. The better such machines are for regulating purposes, the poorer they are for equalizing each other by means of cross-currents.

As to the use of dampers with such synchronous motors, it is difficult to say just what is required. A synchronous motor on a line with considerable ohmic drop is liable to hunt to some extent, especially if the prime mover driving the generator has periodic variations in speed. If the synchronous motor gives very large current on short circuit, then its synchronizing power is high; this will tend to steady the operation of the motor and decrease the hunting. The writer believes that such motors in practice will be found to operate better and have better regulating power for constant pressure if provided with rather heavy copper dampers effectively placed on the field poles. With such heavy dampers reaction of the armature on the field is retarded, and therefore the armature may give a larger momentary current than would flow if there were no damping effect; in other words, the motor is more sluggish than one without dampers. Therefore the addition of heavy dampers on such a machine may produce the same regulating effect which would be obtained by a machine without dampers which gives a larger current on short circuit. Also a machine with heavy dampers will usually be the one with the least hunting tendency and therefore will have the least effect on the transmission line due to hunting currents.

A Synchronous Machine as Regulator and Motor.

In the above, the synchronous motor has been considered only as a regulator and not as a motor. It may be worth considering what would be the effect if the synchronous motor can do useful work at the same time that it regulates the system. In this case, with a given rated output, one component of the input will be wattless, and the other part will be energy. The ratio of these two components could be varied as desired. For example, considering the input as 100, the wattless component could be 60 when the energy component is 80; or the synchronous motor could carry a load of 80% of its rated capacity, this load including its own losses, and could

have a regulating component of 60% of its rated capacity. If the motor is used as a regulating machine only, then its wattless component can be practically 100. It appears therefore that the machine could be used more economically as both motor and regulator than as a regulator alone, but in such case it would probably be advisable to run the motor at somewhat lower speed than if operated entirely as a regulator. This reduction in speed may practically offset the gain in apparent capacity by using the machine for a double purpose. Also there is comparatively limited use for large synchronous motors for power purposes, as better results are usually obtained by subdividing the units and locating each unit nearest to its load. If a load could be provided which would permit very high-speed driving, then it would probably be of advantage to utilize the synchronous motor for driving.

SYNCHRONOUS CONVERTERS AS REGULATORS.

As the synchronous converter is one form of synchronous motor, the question of utilizing such machines for regulators should be mentioned. Upon looking into the question of distribution of losses in the converter, it will be noted that the losses in the armature winding are not uniform. Investigations show that at 100% power-factor the lowest heating in copper is obtained, and that any departure from this power-factor shows considerably increased loss in the copper, such loss being very high in certain portions of the winding. Next to the taps which lead to the collector there are strips of winding which at times are worked at a very high loss. Experience shows that it is not advantageous to operate converters at a low power-factor, and that if so operated continuously, or for any considerable periods, the winding should be made much heavier than for higher power-factors. Also in the usual design of converters the field is not made as strong compared with the armature as in alternator practice, and therefore the regulating tendency of the converter compared with a generator or ordinary synchronous motor, is low. Synchronous converters can and do act as regulators of pressure for sudden changes of the supply pressure, but such correcting or regulating action should not be continual; that is, the pressure supplied to a converter from a line should nominally be that required by the converter for best operation as a synchronous converter. Unless designed for the purpose, a synchronous converter should not be used to correct low power-factors due to other apparatus on the circuit.

RELATIVE COSTS OF SYNCHRONOUS MOTORS AS REGULATORS.

In the above considerations only general reference has been made to the cost of synchronous motors for regulating pressure and power-factors. It is difficult to give even approximate figures for relative costs of such apparatus. As intimated before, there is some mean speed or number of poles which will be the most suitable for giving a certain maximum current on short circuit. For speeds slightly above or below such mean speed, the cost of the synchronous motor should vary almost in proportion to the speed, provided the maximum short-circuit current can be diminished somewhat at the same time. If the speed is further increased or further decreased, the cost will tend to approach a constant figure. As the extreme conditions are approached, the cost will begin to rise. The above assumptions are on the basis of continuous operation at a given current capacity, this being the same in all cases. The above assumption is on the basis of decrease in the maximum short-circuit current, as the machine departs from the mean, or best speed. If the same maximum current is required, then the lowest cost should be at the mean or best speed, while at either side the cost should rise.

It is evident that it would be difficult to give any figures on relative costs of such apparatus. The machine for the best or mean condition, should cost practically the same as an alternating-current generator of the same speed, output, and short-circuit characteristics. As this speed would probably be somewhat higher than usual generator speeds, the cost of such machine would therefore be somewhat lower. This cost would be to a considerable extent, a function of the current on short circuit for a given rated capacity of machine. As mentioned before, in giving a table of limiting speeds and short circuits, it is probable that one-half this limiting speed would be near the best condition. Such machines would probably cost from 60% to 80% as much as similar machines for usual commercial high-speed conditions, neglecting turbo-generator practice. The frequency has considerable effect on this, as, for example, there is small choice of speed as regards high-speed 25-cycle machines. Taking very general figures only, it is probable that in the case of a given capacity of machine for say three or four times full-load current on short circuit the cost cannot be expected to be lower than one-half that of machines of similar rating at ordinary commercial speeds, turbo-generator practice being excluded. The costs in general should approximate more nearly

those of turbo-generators; but again, an exact comparison cannot be made because in usual practice the turbo-generators do not give three to four times full-load current on short circuit.

SOME OTHER ELEMENTS IN THE GENERAL PROBLEM.

There are a number of other conditions in this general problem, such as the advantage or disadvantage of placing synchronous motors in the main power-house, or distributing them in a number of sub-stations. Also there is the question of the effect of the cost on the generating plant when used with such regulating synchronous motors. If higher power-factors are maintained on the transmission system and generator, a cheaper form of generator can probably be used. The high power-factor permits a larger output from the transmission system and thus represents a gain. If the synchronous motor can be operated at its best speed and also do work, then there is a further gain. If the synchronous motor should be located at the center of power distribution, and the power is distributed through induction motors, then there is a possibility of reducing the cost of such motors by designing them for a lower power-factor, this being compensated for by the synchronous motor delivering leading currents. As the cost per horse power of small motors will be much greater than the cost per horse power of a large regulating motor, there is a possibility of gain from this source. If the induction motors are distributed over wide territory, this gain would be lessened and might disappear.

It should be mentioned that the power-factor of a system as influenced by difference in wave form has not been considered in the preceding discussion. It is obviously impracticable to neutralize by a synchronous motor the effect of currents in a system due to difference in wave form. Such currents will in general be of higher frequency than the fundamental wave of the system, and the synchronous motor obviously could not correct for them, unless it impressed upon the system opposite waves of the same frequency. This would mean a synchronous motor with a different wave form from that of the system.

The power-factor of a system will also be affected by any hunting of the apparatus on the system. It is evident that the synchronous motor could not correct or neutralize such effects, except through exerting a damping effect on the system and other apparatus on the system. A synchronous motor with heavy dampers can reduce the hunting in a system, but such hunting can also be damped by induction motors with low-resistance secondaries, especially if of the cage type. This

correcting effect should therefore be credited to the damper rather than to synchronous-motor action. There are a number of other questions which arise in connection with this regulating feature of the synchronous motor, but the subject is too broad to permit even mention of them.

SUMMARY.

The substance of the preceding statements can be summarized as follows:

1. A synchronous motor can be used to establish leading or lagging currents in its supply system by suitable field adjustment, and can thus affect or control power-factor or phase relations of the current in the alternating-current system.

2. A synchronous motor will set up leading or lagging currents in its supply system if its field strength is held constant, and the pressure of the supply system is varied above or below that generated by the synchronous motor. Such leading or lagging currents in the supply system will tend to vary the pressure of the system. A synchronous motor can thus act as a regulator of the pressure of its supply system.

3. This regulating action is greatest with synchronous motors which have the closest true inherent regulation (as indicated by high field magnetomotive force compared with the armature magnetomotive force) in distinction from machines which have close apparent regulation obtained by saturation of the magnetic circuit.

4. If the synchronous motor is used both for regulating the power-factor for neutralizing the effect of other apparatus on the circuit, and for regulating or steadying the pressure of the supply system, its normal capacity for regulating will be diminished.

5. The most suitable speeds for best electrical conditions will in general be considerably below highest possible speeds as limited by mechanical conditions.

6. Heavy dampers will increase the effectiveness of the regulating tendency.

7. If the synchronous motor can be used for power purposes as well as for regulation, its apparent capacity is increased. This is due to the fact that the regulation is obtained by means of a wattless component and the power from the energy component, and the arithmetical sum of these two is greater than their resultant which fixes the current capacity of the machine.

8. Synchronous converters in general are not suited for reg-

ulating the pressure or controlling the power-factor of an alternating-current system.

9. The costs of synchronous motors for regulating purposes will in general be lower than for alternating-current motors or generators of customary speeds, and will approach more nearly to turbo-generator practice.

Discussion on "Synchronous Motors for the Regulation of Power-Factor and Line Voltage."

F. O. Blackwell: In a large plant it is an unnecessary extravagance to figure the copper for a low power-factor when the power-factor can be made 100% by adding leading current to the lagging current caused by induction motors. Even a small lagging power-factor increases the amount of copper very greatly for any assumed regulation.

Rotary condensers are also of great advantage in permitting the pressure of a power transmission system to be regulated at the centre of distribution. It would be perfectly possible to run a power transmission system with rotary condensers in the sub-station without any communication between the sub-station and the distant power-house. The first case of the use of a rotary condenser that the speaker knows of was in a Southern cotton-mill which was equipped with about 4000 h.p. of induction motors and 3000 h.p. of generators. The pressure and the current at the generators was excessive on account of the low power-factor of the load and something had to be done to relieve the apparatus. By installing a rotary condenser of 500 apparent kilowatts capacity in the mill the pressure at the generator, if the speaker remembers correctly, was cut down about 15% and the current was reduced about 20%. The rotary condenser also greatly improved the regulation of the system and avoided the installation of a new generator in the power-house, which would have otherwise been necessary and would have cost several times as much as the rotary condenser.

A 6000 h.p. plant in India, which transmitted power 90 miles, reached the limit of its capacity. The owners decided to increase its capacity by installing a 1000-kw. rotary condenser, and they have been enabled to transmit 50% more power over their existing line, with the same regulation as they had originally with the smaller amount of power. If it had not been for the rotary condenser they would have had to construct an entirely new transmission pole-line.

It is possible not only to maintain 100% power-factor in a transmission system, but also a leading current which will boost the pressure over the reactance of the line and step-up and step-down transformers, so that you can have as high a pressure at the sub-station as at the power-house, or even a higher pressure.

Of course, if a synchronous motor can be used to do useful work it is more economical than a rotary condenser. The most efficient power-factor would be 70% leading, at which point the energy and wattless components of the current are equal. You would then get 70% of the rated capacity of the motor for work and 70% for rotary condenser action.

As Mr. Lamme has pointed out, the high-speed, steam-turbine alternator is not the cheapest machine that can be de-

signed. A speed of about one half that used in turbo-alternators avoids all extreme strains which require special materials and methods of construction and is therefore more economical in design.

W. L. WATERS: This paper is a suitable sequel to the paper which Mr. Lincoln read last year on the "Choice of Frequency for Transmission Lines." Mr. Lincoln showed that if the power-factor on a transmission line was low, the amount of power which could be transmitted over that line, with reasonable regulation, was surprisingly small, and it followed from this that the power-factor should be kept as near as possible to unity.

Mr. Lamme is not quite clear when he describes the effect on the regulation of an over-excited synchronous motor. The beneficial effect of a synchronous motor is entirely due to the leading current, which it takes from the line. The amount of leading current which a motor can take from the line is decided by two things: 1. the margin in ampere-turns, which we have on the magnets. 2. the current in amperes, which the armature can carry.

Both of these are limited by the heating of the magnets and armature, so that, if we are manufacturing a synchronous motor for regulating the pressure on the transmission line, the correct rating of that machine should be the amperes of leading current which it can take when running at a given pressure without the temperature rise of the magnets or armature exceeding 40° cent. The normal rating of the machine and the short-circuit current tell you very little as regards the value of the machine for producing leading currents. We might have a large motor capable of giving a large short-circuit current, which, at the same time, was valueless for pressure regulation on account of the fact that we could not over-excite the magnets because their temperature rise was already high.

As the rating of the motor, as above suggested, is entirely limited by temperature, the force of Mr. Lamme's remark that turbo-alternators are unsuitable for this work becomes very plain. Those who have had experience with these very high-speed machines know that the great difficulty in designing them is to obtain low temperature rises, especially on the field magnets. The other objection to high-speed machines, that they are less reliable in operation, is not of much importance in the case where these motors are used exclusively for regulation of the power-factor. So considering only the question of temperature rise, probably the most economical machine would be one in which the output was about 250 kw. per pole in a 25-cycle machine and about 125 kw. per pole in the 60 cycle.

Mr. Lamme calls attention to the inherent regulating power of a synchronous motor. This effect certainly exists, but under ordinary conditions it is unimportant, and the main

use for the synchronous motor as a pressure regulator would be as a hand-operated regulator. In this respect, Mr. Lamme's statement that "the motor should preferably be one in which the magnetic circuit is not highly saturated," is incorrect, because a motor which had saturated magnets would have a much greater inherent regulating capacity than one in which the magnets were unsaturated; if the motor were infinitely large and perfectly saturated its inherent regulating capacity would be perfect. This statement, as regards unsaturated field magnets, is also incorrect if we consider the motor as being hand regulated, because the effect is one of ampere-turns and not of magnetic flux; that is, assuming the magnetic leakage is not excessive.

The effect of copper dampers on the pole pieces is only a time effect. They slightly delay the effect of a sudden rush of leading or lagging current, but in any case this effect only applies to the inherent regulating automatic action of the machine, so that for all practical purposes the effect of dampers on the pole pieces can be neglected, except as regards their effect on the hunting of the system. In regard to this hunting, Mr. Lamme's statement that squirrel-cage induction motors are more powerful as dampers than motors with coil-wound secondaries and collector rings, is not correct. The damping effect of an induction motor is greater the lower the resistance of the secondary. If we consider modern commercial induction motors, that is, motors capable of starting under full load without taking excessive current, then the resistance of a squirrel-cage secondary is about five or six times that of a coil-wound secondary with short-circuiting device, and in consequence the damping effect of the squirrel-cage armature would be proportionately less.

The question of the use of a synchronous motor running light as a pressure regulator is entirely a commercial question, and the advisability of its use in any particular case must be decided by the question whether the cost of this motor is more than compensated for by the increased output obtained from the line.

H. B. Gear: This question has been discussed thus far with reference to the compensation of systems where the low power-factor was due to lagging current.

In a system operating at 40 000 volts with 200 miles of line the conditions may be reversed, the low power-factor being due to the component of leading current caused by the charging of the line. In such a system the kilovolt-amperes required to charge the lines amount to about 1800. It therefore requires a load of 3000 kilovolt-amperes at 80% lagging to bring the power-factor of this system up to 100%.

The use of a synchronous motor in compensating for a low power-factor on such a system would therefore be limited to the compensation of leading current up to the point where

the load of induction motors reached 3000 kilovolt-amperes. Under certain conditions it might therefore be possible to install a synchronous motor of relatively small capacity, using it during the light-load period to compensate for leading current and during the heavy-load period to compensate for lagging current.

W. B. JACKSON: All of us must appreciate that this paper upon synchronous motors is an excellent and timely one. Although the question as to the proper use of synchronous apparatus has been recognized as quite important for a number of years, yet it is assuming much greater importance as the great transmission systems are becoming more common.

One phase of the use of synchronous motors has not been touched upon in the paper. In the construction of our power transmission plants receiving their power from water, it is not unusual for the hydroelectric portion of the plant to be developed to a point far beyond the minimum capacity of the water. Consequently an auxiliary steam plant is installed to assist during low-water periods. Under such conditions there is often an excellent possibility for the plant to be so designed that the generators in the steam department may be used for balancing motors during the time of heavy load upon the hydraulic plant. It is readily appreciated that at times of low water or of serious back-water conditions the transmission department of the system will be lightly loaded and that, therefore, ample electrical capacity will be at hand to take care of a lower power-factor without difficulty so far as the transmission department is concerned, and at the same time we have the steam auxiliary in operation which will act as the balancing factor upon the system.

Why should not any such plant be so arranged that the engines and generators can be readily disconnected during the times when balancing by synchronous motors is desirable? In other words, when we have the transmission side of the system loaded to its utmost capacity? There is no reason why the possibilities of our auxiliary generator as a balancing motor should be lost sight of simply because it is normally connected to an engine. It is not at all difficult to arrange to disconnect these alternators from the engines and use them for balancing machines, thus making a double use of the apparatus that is installed for the auxiliary plant.

The reversible use of alternating-current generators in transmission plants, either as generators or motors, as the occasion may require, is not uncommon, but the reversible use of the machines as generator or balancing device is quite a different question.

Reference is made in the paper to the possibility of so installing synchronous motors upon the circuit that they may be caused to hold the pressure at the end of the line as high or even higher than that of the generators. There are several

plants where such use has been made of synchronous motors for years past; in fact, there are two plants that the speaker knows of where it has been customary to operate generators at approximately the same pressure as at the distributing end of the line, these being plants where a large part of the capacity of the plant was supplied to synchronous motors, and where it was possible to get into communication with the several synchronous motor installations without difficulty from the power-house. It would probably not be difficult to find plants where it would be practically impossible to operate at all were the synchronous motors now installed replaced by induction motors.

F. A. C. Perrine: The suggestion Mr. Jackson has just made is a very important one, and we all would perhaps be interested to learn that it has been quite extensively used in some Western plants, and in connection with reserve steam machinery for compensating for large leading current on the line, and also automatic compounding of the synchronous motors. For example, in the steam station of the Oakland Transit Company, Oakland, California, supplied by the Old Bay Counties system, transmission of 140 miles, they were compelled to have a steam reserve, on account of fluctuations in pressure. F. H. Baum, one of our members, was called on to determine what could be done, as on account of the very heavy leading current when the load was light the pressure went up, and when the load was heavy the pressure went down. The fluctuations of the pressure were of a serious nature.

Mr. Baum compounded the exciter for the synchronous motors by the direct current, using an extra winding on the exciter, and he arranged this compounding so as to maintain a constant pressure on the system and almost a constant power-factor automatically without any hand regulation of the machine or the synchronous motors. He found, furthermore, by examination with an oscillograph, that Mr. Lamme has apparently not made himself understood on page 300, as he says it is not possible by means of the synchronous motor to correct errors in wave form. In the latter part he says: "such currents will in general be of higher frequency than the fundamental wave of the system, and the synchronous motor obviously could not correct for them, unless it impressed upon the system opposite waves of the same frequency. This would mean a synchronous motor with a different wave form from that of the system." That is exactly what the synchronous motor does at the end of a long line; at the end of a long line the initial wave form is very seriously distorted, and the synchronous motor having a wave form similar to the generator corrects for the variation induced at end of the line.

Again, in some of the mining plants supplied from long-distance transmission lines where the charge has been made on the basis of the maximum current, they have found it advan-

tageous to install synchronous condensers for maintaining high power-factor, the plant being operated by induction motors, the synchronous condenser being used as a reserve steam generator when, by reason of any accident, the power from the transmission line was interrupted.

As regards small plants where it is necessary to maintain a constant power-factor—and the power-factor is already reasonably high, due to the use of lighting load entirely—the synchronous motor as a regulator can be conveniently used, especially where a combined railroad and lighting load are operated from the same generator, and this again, by compounding the synchronous motor through its exciter from the direct-current end of the system. And again, this is used in connection with the steam-driven alternator auxiliary; that is, where a large alternating-current generator is employed during periods of light load, that load can be carried from a separate steam-engine of lower capacity driving an alternating-current generator. When the load rises beyond the capacity of the small engine the latter can be cut off and the load carried from the large alternator through the synchronous motor, the latter being compounded through the direct-current side and thus the power-factor maintained. This does away with the greatest objection to the installation of synchronous motors; the use of the synchronous motor gives the operator control of the whole system.

The matter of cost as presented by Mr. Lamme is surprising; not because he states there is a certain speed at which we find a minimum cost, but due to his statement that the cost of the synchronous converter will be from 60 to 80 per cent. of the cost of an ordinary-speed generator. If we take a generator having about 100 revolutions per minute, ccst will be about ten dollars a kilowatt, while high-speed machines recently sold for four dollars a kilowatt. And this shows, furthermore, that the use of the synchronous motor as a condenser is about as cheap a regulating machine as can very well be obtained. It is a question whether in large sizes there can be built any hand-regulating induction regulators that will cost much less than four dollars a kilowatt, at which to-day these large high-speed machines are actually being sold, and that makes a minimum cost of a high-speed machine about 40 per cent. of the cost of the ordinary-type machine, rather than 60 per cent. The general question is an exceedingly important one, taken in conjunction with the fact that it is possible by the use of these synchronous condensers, especially when connected with direct-current machines, to automatically compound; the same automatic compound may be produced through the exciter by means of the Tirrell regulator or some other regulator of this form. And when we get away from the difficulty and the inaccuracy of hand regulation, we have overcome the most serious objection that has been raised in any of the discussions on the employment of the synchronous condenser.

A paper presented at the 188th Meeting of the American Institute of Electrical Engineers, Chicago, June 21-22, 1904.

LONG SPANS FOR TRANSMISSION LINES.

BY F. O. BLACKWELL.

Many cities to-day are dependent for their lighting, transportation, water supply, and the operation of their industries upon electric power transmitted over considerable distances.

Unfortunately interruptions of the power service do occur not infrequently and when they do happen they so inconvenience the public as to be most conspicuous. The impression that long-distance power transmissions are unreliable has some basis of fact that seriously interferes with their development. Although absolutely continuous service may not be possible, many of the troubles now experienced can be either altogether eliminated or greatly reduced. Among the principal causes of interruption, so far as the line is concerned, may be mentioned:

Short circuiting of lines by branches of trees, wires, or by large birds getting across them.

Burning of wooden pins, cross-arms, and pole-tops by leakage or electrostatic discharges from the conductors.

Burning of wooden poles at the ground from forest or prairie fires.

Failure of insulators from puncture by the current, or their destruction by missiles, discharged maliciously.

Lightning damaging the apparatus connected to the circuits and sometimes destroying poles.

Accidents due to heavy winds overturning the poles or to floods washing them out.

The deterioration of a line requires its replacement in from five to twenty years, depending on climatic conditions and the material which is used in its construction. This replace-

ment of the poles with new ones can only be done by shutting off the current or at the risk of accidental interruptions.

Let us see what can be gained by substituting a steel tower construction with long spans for a wooden pole line. Short circuits are by far the most common difficulty, the only remedy for which is to put the wires so far apart that they are unlikely to be bridged across. This can readily be done even with more than one circuit when a steel cross-arm is employed. Burning is of course entirely done away with where metal construction is used.

Failure of insulators from electrical causes can be obviated by getting larger and better insulators; this is practicable where the spans are long and the number of insulators is small. Insulators on high towers are much poorer targets than when they are near the ground and so are less liable to be broken.

Each metal tower is a lightning-arrester and as they are the highest points in the line they materially assist in its discharge; the tower itself, being a conductor, cannot be injured by lightning. Steel structures can be exactly figured to meet safely any strains that can come upon them and can generally be located only at safe places where there is no danger of washouts. The deterioration of a properly constructed and well-galvanized steel tower is very slight, as is proved by marine and windmill experience, and is practically negligible so far as the pins and cross-arms are concerned. Any part of a steel tower can be readily removed and replaced without interrupting the service.

By far the greatest gain obtained from long spans is in the reduction of the number of parts. If one insulating support takes the place of four or five, line troubles will be reduced nearly in direct proportion; the inspection and repair of the line will be much simplified and its cost of maintenance correspondingly diminished.

Cost of Towers.

The cost of a tower construction as compared with wooden poles depends on the locality. Where the right kind of timber exists, it is of course cheaper; but in tropical countries where wooden poles would have to be transported long distances the towers are much less expensive. In addition, to obtain long life a creosoted wood only could be employed and this still further increases the expense. The fewer insulators and pins and the ease of transportation and erection are in favor of towers. They can be packed in light bundles suitable

for mule-back transportation and quickly put together even in the most inaccessible places. Even where the cost of the tower construction is more it is often justified by the greater certainty of operation which it insures and the lower cost of maintenance.

STRENGTH OF CONDUCTOR.

The first and most important consideration for long spans is the material of the conductor. Copper, aluminum, and iron are availiable for this purpose. Various alloys of copper have great strength, but their conductivity is too low and their cost too high to compare favorably with the more common metals. Copper wire varies widely in its characteristics, depending on the methods used in its manufacture. The copper is received at the wire-mill in the form of cast-wire bars weighing 300 to 350 lb. It is then rolled into rods and the rods are drawn into wire of the required size. The temperature at which the metal is rolled, the reduction of area both in rolling and drawing, and the amount of annealing which the wire is given—all have an important bearing on its characteristics. As the size of the original wire bar is limited, the smaller the wire the more it is worked and in general the better the result.

Cable made up of several strands has the advantage of using smaller wires than a solid conductor, and also permits of longer lengths of conductor without splices. Assuming a 300-lb. wire bar, a 19-strand cable, for example, can be made up weighing 5700 lb. while if solid wire were used the weight of one piece would be 300 lb. In other words, there would be 19 times as many joints with the solid wire as with the 19-strand cable. The smaller the wire and the greater the strength, the more brittle it becomes. This is partly compensated for by the greater flexibility of a cable and the fact that a strand can break without the whole conductor parting.

Each strand should be a continuous wire without joints. Joints in the cable should be as few as possible and made by means of sleeves, as brazing or soldering anneals the wire and much reduces its strength. The permissible tension in the cable must not exceed the elastic limit, by which is meant the point at which the material will continue to elongate and will eventually break, and not the usually accepted meaning of elastic limit as that point at which the strain ceases to be proportional to the stress. Copper cable recently made for a transmission plant with spans of 500 feet had an elastic limit of 40 000 lb.

per square inch; similar aluminum cable had an elastic limit of 12 000 to 14 000 lb. per square inch; galvanized-iron telegraph wire has an elastic limit of 35 000 lb. The ultimate tensile strengths of these wires were 60 000 lb. for copper, 24 000 lb. for aluminum, and 55 000 lb. for iron.

The advantage of aluminum is that it weighs less than copper for the same conductivity, but for long spans its lesser strength, greater diameter, and higher coefficient of expansion are against it. Steel wire has about nine times and iron wire or cable about six times the resistance of copper so that they are more expensive as a conductor than copper. In order to avoid oxidization it is necessary to galvanize iron or steel wire; which partly anneals it and reduces its strength. There are cases where the size of high-pressure line conductors is determined not by resistance but by mechanical strength, and in such cases iron or steel wire can be used to advantage.

Elasticity.

The elasticity of the conductor is of considerable value in reducing the sag when the stress is removed, as will be shown later. The elongation of the wire under stress is less after it has once been stretched. The elasticity of cable is greater than that of solid wire, but both wire and cable take a set under any stress to which they may be subjected. In the following table is given the modulus of elasticity of copper, aluminum and iron wire.

Copper hard-drawn wire	19 500 000
Aluminum hard-drawn wire	10 200 000
Iron telegraph wire	24 000 000
Copper hard-drawn cable wire	16 300 000

Each sample was stretched to a point somewhat below its elastic limit before testing. It will be noted that the copper cable is considerably more elastic than the solid copper wire, the latter being a strand of the cable. The aluminum wire was of nearly the same conductivity as the copper-wire strand and presumably would have had a lower modulus of elasticity if made up into cable. Aluminum is considerably more eaastic and has a decided advantage over copper in this respect.

Coefficient of Expansion.

The coefficients of expansion for Fahrenheit degrees are as follows:

Copper	0.0000096
Aluminum	0.0000130
Steel	0.0000064

As the worst condition so far as sag is concerned is reached when the conductor is hot, a low temperature expansion is most desirable for long spans, and steel is in this respect better than either copper or aluminum.

Strains in Conductors.

The strains upon the conductor are those due to its own weight and the wind acting upon its surface. In a cold climate in addition sleet may form upon the wire, increasing the weight and the surface exposed to the wind. On a line carrying any considerable amount of power it is improbable that sleet will ever form, the formation being prevented by heat due to losses in the conductor. In order to be on the safe side, however, it is best to assume in the North a coating of ice one inch thick all around the conductor. The wind velocity could never exceed 100 miles an hour which would give a pressure of 40 lb. per square foot on a flat surface, or 20 lb. on a cylindrical surface such as that of a wire. The weight is of course a vertical stress and the wind a horizontal one at right angles to the wire. The greatest strain is caused by the resultant of these two. The worst conceivable condition is sleet on the wire, followed by extreme cold weather with high winds. Under such conditions the probabilities are that the ice on the conductor would break off, but without some data on the subject it is hardly safe to assume that this would be the case. In warm climates the absence of sleet and the lesser range of temperature make permissible longer spans than in cold climates.

Sag of Wire.

The maximum sag may be due to the conductor being loaded with sleet or to heating of the wire in a hot sun. The latter will generally be found to give the greater sag. Owing to the conductor being elastic it is not necessary to consider the greatest deflection from a horizontal line between supports as the vertical sag of the wire. The wind pressure causes the wire to swing to one side and it is elongated by the combined strain of wind and weight, but as soon as it is relieved of the wind pressure it swings back to a vertical position and contracts to the length required to carry its weight alone. The sag due to heating of the wire is also somewhat less than it otherwise would be, because when expanded the strain is less and the wire contracts.

The extreme variation of the temperature of the air in cold climates is about 150° fahr., while farther south it does not exceed 100° fahr. To this must be added something for a metal con-

ductor exposed to a hot sun. There are no data upon this but a total variation in the temperature of the conductor of 175° fahr. should be sufficient in any country.

Span and Sag Curves.

The attached curves of span and sag are based on the following data:

	Aluminum	Copper
Area 6-strand cable	0.21 sq. in.	0.132 sq. in.
Diameter 6-strand cable	0.59 in.	0.51 in.
Weight per foot	0.240 lb.	0.509 lb.
Elastic limit	12 000 lb.	40 000 lb.

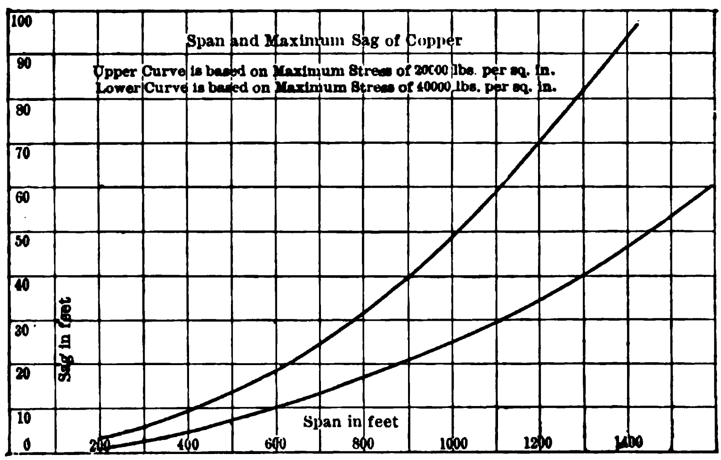


FIG. 1.

Stress at 1/2 elastic limit	1267 lb.	2640 lb.
Stress at elastic limit	2534 lb.	5280 lb.
Wind pressure per sq. ft.	40 lb.	40 lb.
Wind pressure per ft. cable	0.98 lb.	0.84 lb.
Coefficient of expansion	0.000013	0.0000096
Variation in temperature	150° fahr.	150° fahr.
Modulus of elasticity	8 000 000	16 000 000

The equations from which the curves were calculated are given below and alongside of them is an example of a 1000-ft. copper span.

$$D = \frac{S^2 \times W}{8\ T} = \frac{1000^2 \times 0.98}{8 \times 2640} = 46.4 \text{ ft.}$$

In which D = deflection in ft.

S = span in ft.

W = resultant of weight and wind in lb. per ft. of cable

and T = stress allowed in cable in lb.

$$L = S + \frac{8\,D^2}{3\,S} = 1000 + \frac{8\times 46.4^2}{3\times 1000} = 1005.74 \text{ ft.}$$

In which L = length of cable, cold.

$$L_0 = \frac{L}{1+\dfrac{F}{E}} = \frac{1005.74}{1+\dfrac{20\,000}{16\,000\,000}} = 1004.38 \text{ ft.}$$

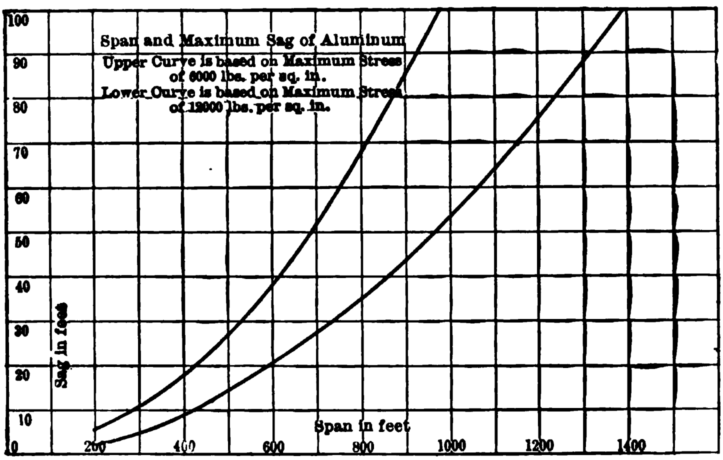


FIG. 2.

In which L_0 = length of cable without stress

F = lb. per sq. in. permitted in cable

and E = modulus of elasticity

$L_H = L_0\,(1+C\,B) = 1004.38\ (1+0.000009\times 150). = 1005.81$ ft.

In which L_H = length of cable, hot (150° fahr. rise in temperature)

C = coefficient of expansion

and B = maximum degrees F. rise in temperature

$$D^3 + \frac{3\,S}{8}\,(S - L_H)\,D = \frac{3\,S^3\,L_H\,W}{64\,E\,A}$$

$$D^3 + \frac{3\times 1000}{8}\,(1000 - 1005.81)\,D = \frac{3\times 1000^3\times 1005.81\ W}{64\times 16\,000\,000\times 0.132}$$

$$D^3 - 2178.7\,D = 22323\,W$$

In which A = area of cable.

From this equation any deflection of the cable can be assumed and the corresponding weight calculated. For instance, in the example if $D = 48.8$ ft., $W = 0.51$ lb.; that is, the sag hot without wind is 48.8 ft., and this is the maximum vertical deflection under the conditions assumed.

If $D = 51.1$ ft., $W = 0.98$ lb. which is the maximum deflection with wind but this is at an angle of 31° from the horizontal and the vertical sag is only 26.6 ft.

The curves (Figs. 1 and 2) give the maximum sag for copper and aluminum cables at different spans with an increase of temperature of 150° fahr. above the minimum temperature. The stresses at the minimum temperature due to wind and weight are limited to half the elastic limit in the upper curves and to the elastic limit in the lower curves. The modulus of elasticity of the copper cable was obtained by experiment, but that of the aluminum cable was assumed by considering its elasticity to increase as much as copper cable compared with solid copper wire.

Height of Towers.

The height of towers is determined by the vertical sag and the clearance required above the ground. If a telephone circuit is below the transmission wires the distance between the telephone and power wires must be added. For instance, if the maximum sag is 12 ft. the telephone 6 ft. below the power wire and the clearance above the ground 20 ft., the tower must evidently support the wires 38 ft. from the ground.

Insulators and Pins.

The insulators and pins must have sufficient mechanical strength to bear the strain transmitted to them from the cable. For example, in the 1000-ft. span just figured on the strain would be 980 lb. per insulator 31° from the horizontal. A properly-designed porcelain insulator will stand any strain that the pin will bear without bending. A rigid cast-iron or steel pin is therefore essential and can readily be obtained.

The Cross-Arms.

The cross-arm is of course subjected as a beam to the weight and wind strains transferred to it from the cable, but in addition there is a torsional strain due to the breaking of a conductor that can best be borne by a pipe. The length of the cross-arm should be sufficient to space the wires well apart and prevent

short circuits either from objects thrown over the line or from the wires swinging together. The former is the more important and if a safe distance apart, say six feet, is chosen it will be sufficient to guard against the latter, as on short spans with relatively less distance between wires they invariably swing together and never touch each other.

CONSTRUCTION OF TOWERS.

The most economical tower construction is one in which the

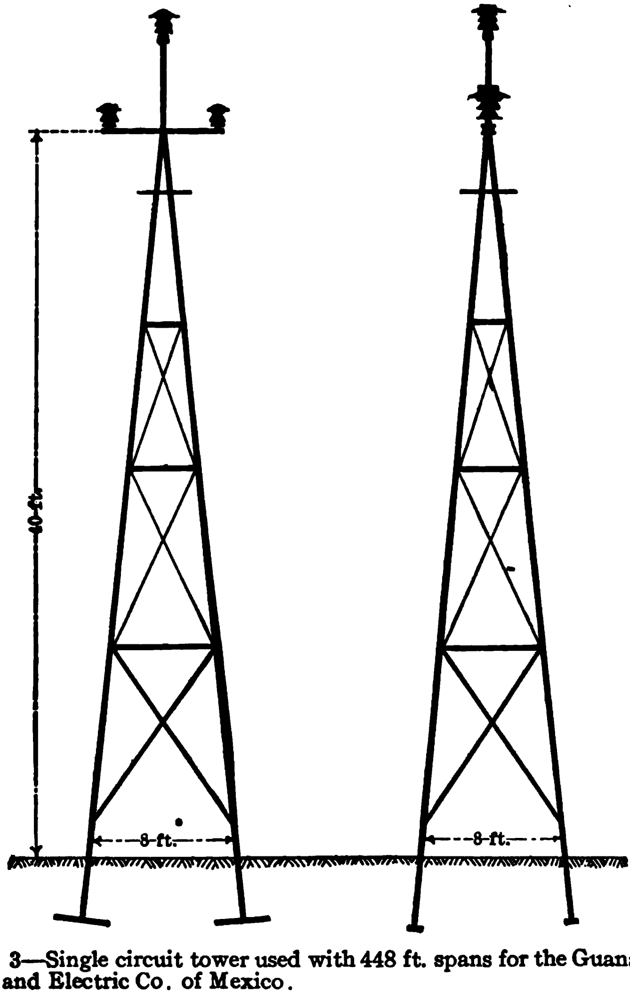


FIG. 3—Single circuit tower used with 448 ft. spans for the Guanajuato Power and Electric Co. of Mexico.

spread of the legs at the ground is about one quarter to one third the height of the tower. If a less spread is used, the

weight of the legs becomes excessive and with a greater spread the cross-bracing must be much increased in size. For a single circuit the common windmill tower construction in which the legs are locked together at the top has the advantage of reducing the strains to a simple compression of the legs on one side and

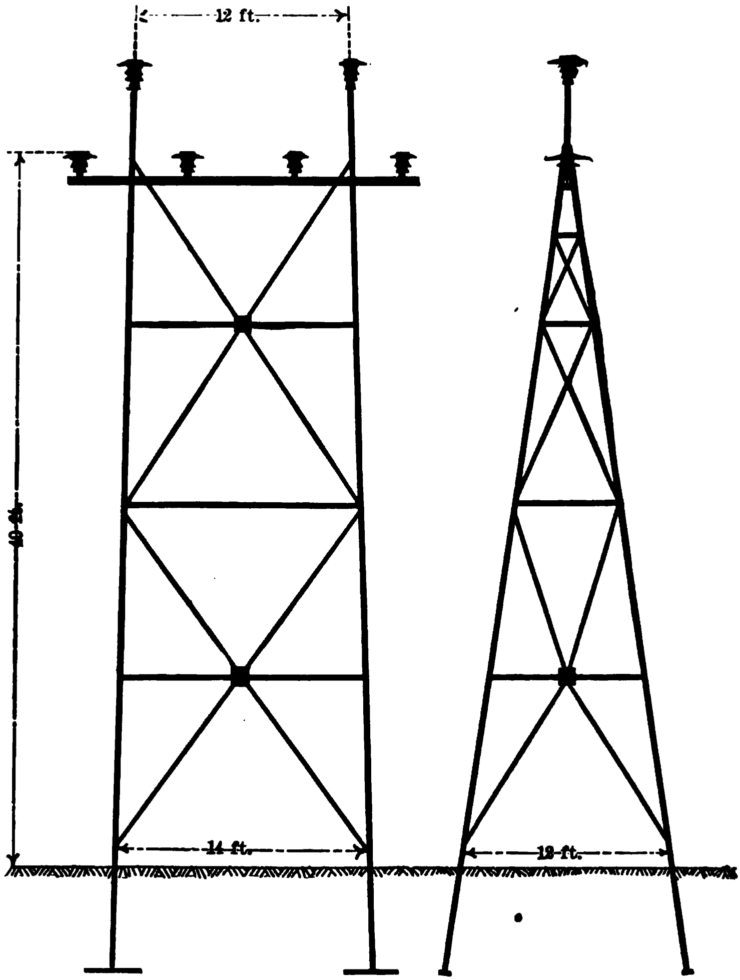


FIG. 4—Double circuit tower used with 440 ft. spans for the Guanajuato Power and Electric Co. of Mexico.

tension on the other, the only function of the cross-bracing being to prevent the legs buckling when in compression.

Where there are two or more circuits the length of the cross-arm is so great as to require two points of support. The tower

can then be made with a width at the top approximating that at the bottom and the cross-bracing has to bear its full share of the lateral strains. A truss construction with the fewest number of parts and opportunities for slack motion and racking of the tower is preferable. Spreading the legs far apart obviates the necessity for expensive concrete foundations, as the strains can be made well within the limits which earth will stand in compression and the weight of earth above the foot of the tower is sufficient to prevent its pulling out of the ground. A heavy galvanizing coating on the tower appears to be an effective protection against rusting and avoids the expense of painting.

Fig. 3 shows the construction employed in the transmission of 101 miles from Zamora to Guanajuato, Mexico, which was the first transmission employing steel towers exclusively. The towers were spaced 440 ft. apart and are designed for a single circuit.

Fig. 4 shows the tower which will be used for the transmission of 90 miles from Necaxa to the City of Mexico, and 170 miles from Necaxa to El Oro, Mexico. These towers will be spaced 500 ft. apart with occasional spans running up to 1000 ft.

The same tower will be used for the transmission of 90 miles from Niagara Falls to Toronto but the distance apart will in the latter case be 400 ft. on account of the possibility of sleet accumulating on the conduotors. There will be two circuits or six wires on each tower and in both the Necaxa and Niagara Falls transmissions noted above there will be two lines of towers making four parallel circuits altogether.

This paper has been intentionally confined to the mechanical construction of transmission lines which the writer believes is more important now than the electrical side. To-day the highest pressure employed is 60 000 volts and the longest transmission 150 miles. There is nothing to prevent the use of higher pressures and longer transmissions, provided reliability can be obtained by a more permanent, substantial, and simpler construction even if the expense is greater. The use of long spans and metal construction is a most important step in the right direction.

DISCUSSION ON "LONG SPANS FOR TRANSMISSION LINES."

RALPH D. MERSHON: At the bottom of page 309 Mr Blackwell says: "The deterioration of a line requires its replacement in from five to twenty years." Presumably Mr. Blackwell refers only to the structure supporting the line. His statement would not hold true regarding the conductors. Of course the whole line does not deteriorate in any such short length of time. On the next page he speaks of the steel tower acting as a lightning-arrester. A few days ago the speaker heard of one line which had been in operation for some time, the construction of this line being similar to that described by Mr. Blackwell. Iron rods were attached to the tower and bent up around the insulator in order to protect it from a stroke by lightning. Has Mr. Blackwell ever seen a similar construction?

Mr. Blackwell also says: "If one insulating support takes the place of four or five, line troubles will be reduced nearly in direct proportion; the inspection and repair of the line will be much simplified and its cost of maintenance correspondingly diminished."

The speaker's experience with line troubles has been that of having less trouble from insulators than from any other part of the construction. Most of the trouble has been caused by forest fires burning the poles; trouble has also been caused by short-circuits due either to wire thrown over the line maliciously or by carelessness in the construction work for extensions, etc.

When a line is first put up, it is almost always the case that a number of the insulators are broken maliciously; after a little while, the insulators are let alone, even in the West. One transmission line with which the speaker was associated crossed a cattle ranch; the cowboys used the insulators for targets, shooting off as many of them as they could. In a short time, however, that practice was stopped, for that class of men, if you appeal to them in the right way, can be easily approached and reasoned with. One of the line inspectors brought the matter home to them by saying that the breaking of one of the insulators might mean the killing of a man at another place, a man who, after touching off a blast, was endeavoring to reach the surface by means of an electric hoist. In that particular case, where trouble of this kind was the worst that the speaker has ever known, it was stopped almost entirely.

On page 311 Mr. Blackwell says: "Permissible tension in the cable must not exceed the elastic limit, by which is meant the point at which the material will continue to elongate and will eventually break, and not the usually accepted meaning of elastic limit." Now what is the difference between what Mr. Blackwell defines there and the ultimate tensile strength which he speaks of on the next page?

There is another matter of importance mentioned by Mr. Blackwell; that is, if a line carries a considerable amount of

power, sleet is not so likely to form on the wire. This is especially true of high-pressure lines. With a given loss, the higher the pressure the smaller the conductor and consequently the greater the loss per unit of radiating surface of conductor, and, so far as the speaker has been able to observe, a small variation in temperature from that at which sleet forms will prevent its formation.

F. O. BLACKWELL: Answering Mr. Mershon's question; of course the deterioration on a line is confined to the wooden parts. Poles, under unfavorable conditions, may rot out in two years. In some places, as in India, ants eat up the poles. In dry ground, with the right kind of wood, the life of a pole may be 20 years. Mr. Mershon also refers to some trouble experienced at Guanajuato which was attributed to lightning. They have had some insulators break there, but, as the speaker understands it, they do not feel certain that the breakage was due to lightning. They are experimenting, however, with an extension of the tower to form a lightning-rod which they will place at exposed points on their transmission system.

Regarding the elastic limit of materials used for conductors, our experiments show that all of them, including copper, aluminum and iron, take a considerable set when subjected to any strain, and that the amount of this set depends on the time during which it is subjected to the strain. The cable is a sort of spiral spring. It is more elastic than a solid wire and its elasticity depends a great deal on the number of twists in the cable, the size of the hemp centre, and other conditions. We used a hemp centre because we found by experiment that a metallic core took the strain to which the cable was subjected before the outer strands and broke first. This made the cable with a conducting core weaker than one made with a hemp core.

Regarding sleet, it is probable that the only time when trouble would be experienced on a transmission of any size is when the power is off the line. At other times there will be sufficient heat generated in the wire to keep it above freezing point. In the case of this Guanajuata construction the insulators were cracked and split open. There was nothing in particular to indicate lightning; they were not burned except so far as they would be by short circuit from the line current.

A. S. HATCH: Possibly the experience of 20 years may be of interest in tower construction. In May, 1884, a windmill tower was erected for lighting a section of Detroit; it was triangular in cross-section, 22 feet on a side at the base and tapering to a point. There are nine 18-ft. gas-pipe sections, the first three being of 2.5 in., the middle three of 2 in. and the top three of 1.5 in., making the total height 161 feet. Weakness has been found to be buckling of the pipe standards, due principally to wind-strains. The towers have not been good lightning-arresters since switch-cases have been punctured after a storm. At the base of the towers are switches to control

the wiring, the cases of which were connected to the tower; and after a severe storm, a switch would be found punctured, showing the lightning had either left the line, jumping to the case of the switch and thence to ground, in case the ground is moist, or, as commonly the case, the lightning leaving the tower for the grounded line. The most common class of tower in use is also triangular but of uniform cross-section, and is built of 2-in. and 1.5-in. pipe, a section being 8 ft. high and 6 ft. on a side. The girts are 1-in. pipe and braced with $\frac{5}{8}$-in. diagonal stay-rods. The base of the tower is a single pipe 15 ft. high on which is a fitting to which both the horizontal and brace supports are fastened. The towers are guyed in four directions by two sets of guy-ropes consisting of 0.5-in. steel strand fastened to wooden stubs. These towers vary from 150 to 175 feet high, and on account of being used in a city are preferable, but the taper tower is better for transmission purposes on account of avoiding the use of stubs. There is no side-strain except that due to the line-wires fastened to the tower and sometimes having a span of 250 feet from a pole.

CHAS. F. SCOTT: The subject covered by Mr. Blackwell is a most timely and important one. It is notable that this paper deals mainly with mechanical problems, and that those which are particularly electrical in their bearing are minor in number. In fact, after the electrical engineer specifies a few general conditions as to conductivity and gives his attention particularly to insulators, the rest consists of matters which pertain to mechanical and economical problems.

Mr. Blackwell has pointed out the principal causes of the interruption of lines as they are now constructed. The new type of construction moreover apparently removes in a large measure all the principal causes of interruption to service in present lines; this is a very strong argument for the tower construction.

The discussion in the paper with regard to the characteristics of conductors and making comparison between copper, aluminum, and iron are of much interest, particularly the data upon copper cable. The difference between the elasticity of the wire and the cable, the latter being, as Mr. Blackwell expressed it, in the nature of a spiral spring, is noteworthy. One of the elements in this type of construction is the probable change in length of the conductor due to temperature variation. If the conductor could be made a spiral spring or if the twisting of the cable could even be carried to a greater extent than it is in the ordinary cable, then the conductor might be given a great elasticity and the limitations which are reached due to the variable sag of the cable might, in a measure, be eliminated.

Mr. Blackwell did not state specifically the pressure which is used on the line to which he refers. The inference is, however, that it is 60 000 volts.

N. J. NEALL: Has Mr. Blackwell any data to show the value of steel towers as lightning-arresters compared with standard lightning-arresters? and does he know of any case where steel towers were struck directly by lightning and what happened?

F. O. BLACKWELL: The speaker knows of a number of transmissions using pipe poles. In general it would appear that there is less trouble from lightning with an iron than with a wooden construction. Should lightning actually strike the line it would naturally go down the first pole. It would do no damage to a metal pole but would shatter a wooden one. With wooden poles there was always evidence left in the burning of or splinters from the pole, but with an iron pole you might have a stroke of lightning and never know it, except for a short circuit on the line, or unless an insulator were broken, which is rather improbable.

N. J. NEALL: Let us assume a case of a 60 000-volt transmission line in a mountainous country, such, for example, as in the far West. How would the cost of steel towers compare with the best present wood pole construction?

F. O. BLACKWELL: The comparative cost of steel towers and wooden poles can hardly be definitely stated, as it varies with the locality and the conditions. In this country, a wooden construction would almost invariably be cheaper as the tower system would be about equivalent to a cost of, say $10.00 per wooden pole. The steel tower in the tropics, where wood will not last any length of time, is essential; in this country, the speaker considers the use of a metal construction preferable on account of its more permanent character. The use of steel for long-distance transmission will probably supplant wood in order to get a more permanent and reliable construction. Where there is more than one circuit on a pole the necessary distance between conductors—to avoid the danger of short-circuiting—requires such a long cross-arm that it is essential to use two wooden poles in order properly to support the cross-arm. This, of course, doubles the cost of a wooden pole-line but makes practically no difference in the cost of a steel-tower construction.

A cable is preferable to a solid wire because it is more reliable and more elastic. The cable is flexible, which makes it less liable to damage during construction and from the swinging of the conductor in the wind. Should one strand of a cable break the whole conductor will not come down and the broken strand can be repaired at any convenient time. With a cable we can use a more brittle wire which has a much greater strength per square inch than would be possible safely to employ were a solid conductor used.

Regarding telephone circuits, it does not appear to the speaker that there is any disadvantage in the use of a metal structure; in fact, there is an advantage in that it is impossible

for high-pressure current to leak from the tower wires to the telephone circuit as it could on a wet wooden pole, which is a conductor of high resistance, whereas the tower is always grounded. It is most undesirable to do any work on a high-pressure circuit when it is alive. Wherever possible, multiple circuits should be employed so that one of them can be cut out for repairs without interrupting the tower service.

WM. HOOPES: A few words may be devoted to the aspect of this paper towards the comparison drawn between aluminum and copper for work of this character. By inspection of page 314 of the paper, it would appear that a sag of aluminum of 53 feet may be expected in a 100-ft. span.

Two and one-half years ago, the Pittsburg Reduction Company erected on a bluff 300 feet high, on the Allegheny River, in one of the most exposed situations in Western Pennsylvania, four 1000-ft. spans of No. 0000 aluminum wire, for the purpose of determining what might be expected from such a span.

Observations taken on these spans on June 17, with a temperature of 80° fahr., showed a sag of 22 feet. As the sun was shining at the time the observation was taken, the temperature of the wire should be taken as 105°, using the figure assumed in the paper as being correct; *i.e.*, that the wire would be 25° hotter than the air, due to the sunshine. The minimum temperature since the spans were erected was –14°, making a total range of temperature between the minimum and the time of observation of 119°. The paper assumes that a further rise of temperature of 56° may occur; if it does, the sag of the wire will be 27 feet. There is therefore considerable discrepancy between what actually has happened in such a span (which is about representative of what is likely to occur) and the 53-ft. sag which the paper says may be expected.

The reason for this discrepancy is the difference between the conditions which have actually occurred and the conditions which the paper contemplates as possible. The conditions contemplated by the paper are:

1. That the wind will blow with an actual velocity of 100 miles per hour.

2. That such a wind velocity will be coincident with minimum temperature.

3. That the direction of the wind will be at right angles to the line.

If any section 100 miles square were selected and a pole line built across it, by assembling what data is available from the U. S. Weather Bureau and applying the theory of probabilities, we would find that a combination of these conditions is not likely to occur oftener than about once in 20 000 years.

The Government reports give the velocities as actually indicated by the standard anemometer. These figures require a considerable change to convert them to true velocities. One hundred miles actual velocity would be reported as 135 miles

per hour. Such a velocity is almost unknown in the annals of the Weather Bureau. A search of the Bureau reports for six years shows for 28 widely scattered stations a maximum indicated velocity of 86 miles, or an actual velocity of 68 miles per hour. None of the maximum velocities have occurred coincidently with low temperatures and it does not seem within the range of probability that they will so occur. The maximum velocity occurring in Chicago last winter when the thermometer was below zero was 38 miles per hour indicated.

The only wind which actually seems likely to do harm to a line of this character is a tornado, and which it is impossible to erect any line to withstand, since the effects of tornadoes have been observed which must have been due to an actual velocity of 300 miles per hour, or a pressure of 360 pounds per square foot. Provision against this would involve a cost of construction absolutely prohibitory. Aside from the tornado the most severe condition a long span line is likely to be called upon to withstand, so far as wind strain is concerned, is a wind velocity of 40 miles per hour, occurring at from 20 to 30 degrees above the minimum temperature.

Although the conditions assumed in the paper seem unlikely to occur, it is worth while to consider what would take place with a line not designed to meet these conditions but to meet those which actually seem probable. Such a line using aluminum of the size referred to in the paper would be erected to have a sag, at minimum temperature, of 13.25 feet, and a tension of 11 000 pounds per square inch, the elastic limit being 14 000 pounds per square inch. If in that condition it were subjected to a 100 mile wind, at right angles, the effect would be to stretch the wire, not to break it, so that a sag of 42 feet would take place, which upon cessation of the wind would become 38 feet.

The effect upon the wire would be permanently to stretch it about four feet. It will withstand an elongation of 16 feet before rupture, and there really exists, therefore, a factor of safety of four, against breakage, even when the improbable conditions here chosen are used as the basis of calculation.

It is to be noted that in the case of spans of wire, the real factor of safety is not the ratio between the strength and the strain, which is the usual definition, but the ratio between the elongation at rupture and the possible elongation.

With regard to the strains due to sleet, there seems to be no limit to the amount of sleet which may gather on wire and it is very doubtful if the assumption of a depth of one inch for the deposit provides for the probabilities. If it is to be considered at all, a greater thickness should be considered as possible. However, the opinion of most practical transmission engineers, based on experience, seems to be, that sleet does not form on high-tension wires, and that its consideration does not therefore constitute an element of the problem.

With regard to the necessary strength of supports, and therefore their cost, the most severe requirement is most lightly touched on in the paper. This condition will be when, for any reason, all three conductors part in the same span, leaving the unbalanced strain to be taken care of by the supports, which supports must be strong enough to withstand this strain, as in the event of such an occurrence several miles of the line might go down, if they are not so constructed. If the supports are made strong enough to meet this condition, they will be amply strong enough to meet the wind strains calculated, since the side strains due to the wind are less than one-fifth the longitudinal strains produced by this condition. It also becomes apparent in this connection that, if a maximum strain per conductor of 5000 pounds for copper and 2500 pounds for aluminum is allowed, the towers will have to be twice as strong for copper as for aluminum. If, on the other hand, the strain per conductor is to be kept down to 2500 pounds, the maximum sag of the copper will be about the same as that of the aluminum, instead of about one-half as much, as shown in the paper. The expediency of allowing the amount of sag designated appears very doubtful, since, if the improbable conditions assumed do occur, the only effect will be, not to break the wires and interrupt service, but to introduce a sag, which can be removed at leisure. To allow the amount of sag calculated, if not necessary, forfeits considerable advantage, because if such a line were constructed on 75-ft. towers, for instance, and a sag of 50 feet allowed, the wires at the center of the span, being only 25 feet from the ground, could easily be short circuited by malicious persons. On the contrary, if a sag of 30 feet only be allowed, (which is all that is probably necessary), a clearance of 45 feet is obtained, and malicious interference becomes very difficult, and, therefore, improbable.

It would appear to be the best practice on a line of this sort, to erect the conductors so that they would reach a maximum tension at a minimum temperature of about 80% of their elastic limit, without considering the wind as a strain producer. If this is done, it will be only on very rare occasions that the wind or other causes will permanently stretch the wires and produce a greater sag than is contemplated, and this, when it does happen, will be on short stretches of the line only, making repairs a matter to be done at a convenient time and at very slight expense.

One result of following the method of calculation in the paper is that the sag to be allowed for every different size of wire would be different, although the wire is of the same material. This is because the wind pressure varies directly as the diameter of the wire, while the strength to resist the wind pressure varies as the square of the diameter. If the calculations on which the paper is based had been made for No. 1 copper, instead of No. 000 copper, the results would have been entirely

different and the maximum sags to be provided for very much greater.

F. O. BLACKWELL (by letter): Referring to Mr. Hoopes' comments, the writer affirms that it was not his intention to lay down any rules for the sag employed in long spans but to give the data and formulas which can be used in figuring upon them.

The maximum strain in the conductor and the wind pressure which should be assumed are matters of engineering judgment. A wind pressure of 40 lb. per sq. ft. is that commonly employed in making the calculations upon practically all engineering structures, and, therefore, the writer would not take any less pressure without further data on the subject. A long-distance transmission line may cover a great deal of territory and if there is any high wind it is most likely to be interrupted by it. The fact that an isolated span with much less sag has been up for two or three years does not necessarily prove anything. The probabilities are that at the particular point at which the experimental span was erected no high winds have been experienced.

It does not impress the writer as being good engineering to put up a long span and then let it take its own sag by stretching the wire as Mr. Hoopes suggests, any more than it would be advisable to do the same thing in a suspension bridge.

The writer does not agree with Mr. Hoopes regarding the strains to which towers are subjected lengthwise of the line. The ordinary tie-wire which attaches the conductor to the insulator will not bear any considerable strain. If a conductor breaks it always slips over the insulators for a considerable distance on both sides of the break and distributes the strain, due to the tension in the conductor, over a number of insulators and towers. As Mr. Hoopes states, the amount of sag to be allowed varies with different sizes of wires. Each transmission must therefore be calculated separately and no tables or curves can be given which will cover all conditions.

EUGENE CLARK: The speaker is particularly interested in the paper by Mr. Blackwell, because he argues for better mechanical strength in the pole line, which is generally conceded to be the weakest point in an electrical system. The speaker thinks it possible, however, that Mr. Blackwell might have left the impression that line construction with steel poles would be just as cheap as similar construction with wooden poles, and if this were true, he wishes to offer a correction to that impression. The speaker objects to the figure of $10.00 a pole which Mr. Blackwell has submitted as the equivalent in wood, of steel construction, The speaker knows that steel poles have long been in use in many steel plants of the country, not for the purpose of securing longer spans for light wires, but for the purpose of securing better mechanical construction for the exceedingly heavy lines necessitated by the large amounts of power carried at low pressures in such plants.

That the cost of such poles, which are quite heavy, varies from $60.00 to $120.00 each, erected, including cross-arms, concrete foundations, etc. One steel company has recently had occasion to cross a navigable river, and to do so found it necessary to put up very high steel towers. In this case, the total cost of each tower amounted to more than $1500.00.

The speaker believes thoroughly ,however, in the advisability of the superior mechanical construction made possible by the use of steel poles, calling attention to the fact that moving machinery, such as cranes and hoists, is commonly designed with factors of safety of from 5 to 8; whereas, the factor of safety on pole lines, as frequently constructed, scarcely amounts to 2 or 3 for ordinary service. The factor of safety should be at least as high on a pole line as on moving machinery.

President Arnold: The New York Central engineers also investigated pretty thoroughly the matter of steel poles. They began with steel poles that cost approximately $200 each; by dint of much effort they were finally estimated to cost abcut $80 each. The argument in favor of steel poles is strongest for the long-distance transmission lines running across country where the poles can be spread as far apart as will be justified by mechanical consideration. In cities the poles must be placed close together, necessitating the use of a larger number of steel poles per mile of line than would obtain in the country; this increases materially the cost of the line as obviously steel poles cost more than wooden ones. As Mr. Blackwell says, where the wooden poles are expensive, as in Mexico, the transportation of wooden poles is likely to make them cost as much or more than the steel towers. On the Guanajuato plant the cost was much less with five steel poles to the mile than it would have been with wooden poles spaced the ordinary distance apart. So the question is always one of the relative cost of wood versus steel *in position*. In the speaker's opinion there is no doubt about the desirability of steel poles; the question is rather one of getting sufficient poles to carry the line at a price that will justify their use.

The engineers of the New York Central road have decided upon overhead transmission for most of the line and for these two reasons: first, less first cost; secondly, the likelihood of less trouble with overhead lines than with underground cable—all this notwithstanding Mr. Carlton's statement. His statement is undoubtedly correct, but it seems that he refers to a specific case. The evidence in the New York Central case showed that they might expect less trouble with overhead transmission lines running across country than with an underground cable. For these reasons cable is being installed only in New York and its vicinity, where the use of cables is practically compulsory. A pressure of 11 000 volts will be used on this system. There will be six wires, two circuits, and the spans will be made as long as the conditions will admit. There

is quite a number of curves in the track which necessitates putting the poles closer together than in an ordinary construction. The bridge engineers of the company are figuring the relative cost of poles; the poles are approximately between 16 and 18 inches at the base and 45 ft. high.

In further explanation of why the engineers of the New York Central adopted the overhead plan it might be said that the possibility of trouble on the line was taken into consideration; for with overhead construction trouble can be located and remedied quickly and easily, much more so than would be the case with an underground cable. The objection to cable seems to be that when anything happens the trouble can be neither located nor repaired promptly.

EUGENE CLARK: It does not make so mucn difference about the angle-iron, if the rails are good in the first place, but the construction of the pole must be rather unusual. The common poles that the speaker referred to as costing \$60 and \$120, consist of four irons latticed together, on the other side with rounds to form the ladder. The speaker does not see how you can get that amount of steel in for \$15, if it is steel.

W. D. BALL: The South Side Suburban Railway Company of Chicago has ordered a few poles on trial, and information regarding their cost and weight may be of interest. The poles in question were 30 ft. high, weighing 616 lb. each, and the price f.o.b. cars Chicago or vicinity was a little less than three cents a lb. The actual cost of the pole is considerably less than any other type on the market, as it weighs less for any given strength and the cost per lb. is a trifle less, as tubular poles were quoted from three to three and a half cents. The construction consists of three U-section steel uprights tied together with special malleable castings every two feet or 30 inches. The poles in question were six inches, at the top and thirteen inches at base.

RALPH D. MERSHON: There are two matters in connection with steel towers which have not been referred to; one of them is the amount of torsion that the steel tower shown by Mr. Blackwell can resist in case one or more of the conductors should break. The speaker knows of one instance where a latticed steel pole was erected, where no allowance was made for torsional stresses with the result that every time a wire broke there was considerable trouble.

Another matter in connection with steel supporting structures with long spans is the question of repairs. A span of say 150 feet is easier to repair than a much longer span; this means that in case of a break in the line the power service will be interrupted for only a comparatively short time. In comparing this type of construction with other types the first cost alone should not be considered; we should consider everything which goes to make up the total cost; first cost, maintenance, etc.

It seems to the speaker that there is one point in which the steel tower construction falls short of what is claimed for it. Although it is true that the conductor will, for the greater part of its length, be higher than an ordinary pole-line, still with the construction described by Mr. Blackwell, the conductor is only about 25 feet from the ground, making it easy to short circuit the line at this point with a bale wire as in the case of a shorter span and lower pole.

N. J. NEALL: The following facts should be borne in mind with respect to the development of steel towers; some of the more recent wooden pole constructions are very stable; a number of lines have been built with a great deal of attention to the mechanical features, heavier poles and greater strength throughout, and the maintenance of an almost continuous line servicc for a year or more would indicate that the wooden pole line has been developed very materially. When you have such a construction near the base of supplies, it may require more than the arguments brought out to-day to substitute steel towers for wood. In the case cited by Mr. Blackwell where wood is as difficult to obtain as steel, it is perhaps more economical to make use of the steel tower. In cities and their outlying districts still other conditions enter, and it might be easily advisable that the tower construction, even though more expensive, should be employed.

In addition to the emphasis given the advantages pointed out by Mr. Blackwell for metal towers, it does not appear from the discussion that the cost of such a tower construction is, broadly speaking, prohibitive. The advantages of the metal tower as a lightning-arrester seem to be unduly emphasized. The metal tower might be considered as having approximately the same discharge value as an overhead grounded wire on a wooden pole-line, and it is obvious that in view of the fractional value of such protection we are in no degree relieved from having protective apparatus in the stations. The discharge value of the metal tower seems only incidental to its other advantages.

CHAS. F. SCOTT: We are getting on the wrong line of discussion with reference to Mr. Blackwell's paper. While the cost, the relative cost, of the two different types of construction is an important thing to consider, it is not the only thing. Mr. Blackwell does not begin his paper with the consideration of cost or to find something that is cheaper. He begins it: " Unfortunately interruptions of the power service occur not infrequently and when they do happen they so inconvenience the public as to be most conspicuous."

It is a better kind of service, a different order of construction that he is seeking for; he finds out how that construction will overcome present difficulties. Sometimes cost is important; sometimes it is relatively unimportant. A few years ago an engineer who was making a preliminary layout of a trans-

mission plant asked the speaker what he thought of the engineer's transmission system; it was 20 miles in length, and he proposed to use one pole line and two circuits of 30 000 volts. The engineer was told that his pressure was very high and he was putting a good deal on a one-pole line, and as he wanted reliability he would better consider lower pressure and two separate pole lines. The cost of the line complete, conductors, poles, insulators—the whole cost as the speaker remembers—was something like four per cent. of the total investment. Here, then, was the element in the system upon which the continuity and reliability of service depended—the most vital element in the whole system, and he had gotten it down to four per cent. of the whole investment. By increasing that element, say doubling its cost, and running two pole lines say of 20 000 volts each, he would increase his total cost only a few per cent. and he would increase his coefficient of reliability by a very much greater per cent. So in the general question now under discussion, we have to consider, first the general engineering condition, which would be the best plan and would give the most reliable service; and then determine as to the cost. This paper should be considered on its general engineering merits, and it seems to the speaker that Mr. Blackwell's points are pretty well taken.

Another thing: we have been comparing a new type of construction with certain lines and poles now used. We are coming into a different order of conditions in power transmission—the circuits are of greater output, higher pressure, and greater importance. Where there are many circuits, with large and heavy wire, where continuity of service is of the utmost importance, where the cost of the line could often be considerably increased in order to increase the coefficient of reliability, then we must consider the problem from an entirely new standpoint. In these respects the lines laid down in this paper are very promising.

F. A. C. Perrine: While agreeing entirely with Mr. Blackwell and Mr. Scott in the statement that reliability is more important than cost in long distance transmission, the speaker believes that a number of points raised by Mr. Blackwell require consideration.

As regards the limit of transmission with any particular size wire it may be noted that up to 40 000 volts no wire of sufficient strength to be employed in a transmission line is small enough to allow discharge through the air, consequently allowing the rule that the practice in transmission pressure is to employ about 1000 volts per mile. The question of limiting size of wire is not of importance until the distance exceeds 30 or 35 miles. For longer lines where the pressure is between 40 000 and 60 000 volts no wire smaller than $\frac{3}{8}$ in. in diameter may be used; since Mr. Scott has already shown in the paper referred to that at such pressures a wire $\frac{1}{4}$ in. in diameter will discharge

a large amount of energy. This necessity for the use of a large wire on long lines is one of the advantages in the use of aluminum, an advantage not noticed by Mr. Blackwell in his paper. This is particularly an advantage of aluminum, since where small amounts of energy must be transmitted over a wire of a definite size the loss is not important, and the aluminum wire is very much cheaper than the copper wire of the same size. These large wires are invariably made stranded, as in this form they are more reliable than any solid wire of the same area, on account of the fact that the smaller wire has a high tensile strength and by reason of the fact that the weak places are distributed along its length. The writer believes that Mr. Blackwell is in error when he states on page 557 strands are made of unjointed wire. The practice amongst manufacturers being to joint reel after reel in their machine, cutting off the completed strand in the required lengths without reference to the lengths of wire on the spools of the machine which are jointed as required. Experience has shown that the large strand which must be employed in very long lines gives no trouble in breaking.

The speaker knows of very few instances where strands of over 0.5 inch in diameter have been burned off; the few cases occurring have been due to a solid short circuit where the station fuses did not operate, but it is generally the case that the station fuses operate before the line wire is fused.

Attention must be called to an additional advantage of tower construction, that it permits the use of large cross-arms supporting the very heavy insulators which must be used in the higher pressure construction. Insulators at present weighing from 30 to 50 pounds are common, and with electrical pressures increasing the present tendency is toward larger insulators weighing as much as 100 pounds. Some insulators now in use cannot be installed on a wooden cross-arm less than 6 by 6 inches, which arm cannot be securely supported on a wooden pole with a 9-inch top. In consequence the steel tower, whether the cross-arm be of steel or wood, is probably capable of furnishing the more reliable type of construction, since in long-distance transmission lines we must decrease the number of insulators by lengthening the spans and correspondingly increase the size of the insulator. This can only be accomplished by the use of the steel tower.

The value of the steel tower as a lightning-arrester the speaker considers very important. He believes that to-day the advantage from the use of a grounded wire for protecting the long-distance transmission lines is unquestioned, though there is decided difference of opinion concerning its permanence; but with the steel-tower construction a sufficient number of grounded points are brought close to the wire without the use of an extra wire. On one transmission line with which the speaker is familiar there is a section 37 miles in length where the average

span is 300 feet; this section is one-third of the line and extends over a series of low hills. Such lines can undoubtedly be made more permanent if steel towers are used in place of the wooden poles. While not an advocate of the steel-tower construction for short lines and low pressures, the speaker strongly believes in the steel-tower construction for long lines and high pressures; first, because of the increased value of insulation by reason of a lesser number of insulators; secondly, because of the lightning protection afforded; thirdly, because of the permanence of the towers themselves, and because of the fact that they allow the use of a cross-arm which will support a larger insulator and a larger wire.

Finally the speaker would call attention to what he believes to be an error in Mr. Blackwell's Introduction, pages 314 to 316, where he makes use of the standard coefficient of linear expansion in calculating the temperature changes. This is not correct unless the modulus of elasticity is introduced into the equation, which then becomes too complicated for solution. If a fictive coefficient of expansion based on experiments at different temperatures with actual spans, then the form can be considered correct.

The equivalent cross-section of a solid wire will have a lower tensile strength than a strand, because the wires of a strand have been subjected to an increased amount of working and are consequently harder. Furthermore the weak places in a strand are distributed. In consequence the strength of a strand is proportionally more than one would expect from the decreased size of the wire.

RALPH D. MERSHON: Does Dr. Perrine mean that the ultimate strength of the cable will be greater than the sum of the ultimate strengths of the individual wires?

F. A. C. PERRINE: Yes; so far as the speaker knows, with copper, with soft strands. That is absoultely untrue with steel, with metal that will not crush.

EUGENE CLARK: The speaker calls attention, as being of interest in this connection, to the fact that hoisting ropes used on cranes built to handle molten metal have been made with cores of soft iron wire, or of asbestos, it being necessary to use a fireproof material. In practice, it is found that the strain on the ropes acts to extend the helices formed by the outside strands of the rope. In the case of asbestos-cored rope, the core would break at various points throughout the length of the rope and separate, so that sometimes 18-in. or 24-in. space intervenes between the two broken ends of the core. The result would be to allow the rope to flatten at that point. In the case of the soft iron-cored ropes, the iron core was cut out of the rope at each end. When the rope stretched, the iron core was stretched enough to pull through and leave the open space at each end of the rope, where it caused no damage. In view of these facts, the speaker feels convinced that a central straight strand for a

transmission cable would certainly receive more strain than the outside strands.

RALPH D. MERSHON: It seems to the speaker that Dr. Perrine overrates the question of lightning protection from steel towers. The speaker does not see how a steel tower can be the equivalent of a ground-wire, nor how a steel tower can ward off electrostatic induction. The tower might take a lightning stroke, but it does not seem that it could be of any protection from effects due to electrostatic induction or from lightning strokes which might get into the line-wire. In the latter case the charge will probably jump to a pole, but in doing so will probably shatter an insulator. The speaker does not recall any case where a wooden pole has been shattered by lightning where the insulators on that pole have not, one or more of them, been shattered. It isn't a case of simply flashing-over the insulator, nor is it a case of flashing-round or yet a case of puncture. In most cases the insulators go all to pieces; the speaker knows of one case where a pole on a high-pressure line was struck by lightning and an insulator smashed to pieces; the French Canadian patrolman who reported upon this occurrence said in his report: " I found pieces of her over in the field; if she had been hit by a stone she would not have gone so far."

Dr. Perrine and Mr. Scott have both said the cost is not the important question. This the speaker cannot agree with, for he believes that cost is the only question; not necessarily first cost but the total cost, including interest, depreciation, etc. Into this cost must enter and be considered the question of reliability, a question which cannot easily be evaluated in dollars and cents. Its weight and valuation must enter into the calculation through the medium of the engineer's judgment. It is easy to imagine a situation where, with a type of construction subject to mishaps resulting in interruption to service, a plant might be a commercial success in spite of occasional interruptions, but where the cost of absolutely reliable service would swamp the enterprise; on the other hand, there are situations where anything less than the very best and most reliable construction would swamp it. It is all a question of cost, and of cost proportional to the conditions to be met.

W. B. JACKSON: The speaker fully agrees with the statements that the iron tower would seem to be excellent as a lightning protection.

The speaker does not agree with Mr. Mershon that the lightning in jumping around the insulators as a rule breaks them. For instance, in a 20 000-volt transmission line, with which the speaker is familiar, the lightning has struck the line a number of times and smashed one or more poles at or near the point of striking and has then run along the line each way jumping around the insulators for several poles consecutively, slightly splintering the poles. It was seldom the case that the insulators were broken in the discharge of the current over

them. It was usually possible to replace the broken poles by setting a new pole immediately alongside of the broken one and transferring the cross-arm and the pole-top insulator without further repairs. In the case of the steel towers there would apparently be little tendency toward the destruction of the tower, and should the lightning strike the line it would have a tendency to run along the line and relieve itself over the insulators at the adjacent towers.

Referring again to the line mentioned before; it was not infrequently struck at points between the lightning-arrester stations, and sometimes struck hard without any indication whatsoever of the discharge getting as far as the lightning-arrester stations, though indications of its leaving the line over the insulators was amply abundant.

As already indicated it is entirely possible that the lightning might strike between the supports in the case of iron towers and run either way along the line, dissipating itself through induction and by discharge to the towers. Of course the exact action under these conditions cannot be predicted with any certainty, especially as with the steel-tower construction we generally associate the higher pressures such as 60 000 to 80 000 volts, and so must solve the problem according to our best judgment considering that we have no operating data to work upon—but we must always remember that lightning works according to ways other than our own.

There is another feature in connection with the tower construction that has been brought out a very little this morning, that would seem to warrant further consideration. It has not been uncommon on 20 000-volt transmission lines and even 30 000- and 35 000-volt lines that a wire of the transmission circuit has dropped on to the cross-arm carrying wires and no one has been the wiser for the fact until the line inspector discovered it. In the case of the steel tower, the dropping of one of the wires upon the support might be indeed serious, owing to the fact that the wire would probably be burned off at the point of contact, with disastrous results; thus the problem of the mechanical strength of the insulator and the attachment of the cable thereto is of paramount importance. As Dr. Perrine has pointed out, there is extremely little chance of a properly constructed cable breaking except under abnormal conditions, therefore, the absolute certainty of support of the cable is of the greatest importance, for if there is danger of the insulator breaking, or the attachment of the wire to the insulator giving way, the possibility of the wire being burned off would be considerable. With the long spans and heavy cables that would usually be contemplated in connection with steel towers, the breaking of the wire might be a catastrophe of real magnitude.

Except in extraordinary situations, the speaker's feeling is that a well-constructed pole line using wooden poles and wooden

cross-arms must continue to be the most satisfactory construction for transmission lines, so far as general practice is concerned in this country.

A conversation which the speaker had with Mr. Blathy of Ganz & Company at Budapest may be interesting: he remarked that it would be unwise to attempt to employ 35 000 or 40 000 volts in accordance with the usual European practice in transmission work considering the status of the insulator at that time, and asked: " What do you think would be the best to do under the circumstances? " My reply was, to use the usual iron poles but attach wooden cross-arms to them. He replied that they would not permit such unsightly construction as this would necessitate, though he felt that the wooden cross-arm was a material advantage.

H. B. Alverson: In regard to lightning on lines of 11 000 volts and 22 000 volts, our experience has been that where it struck, the insulators would be shattered. Either way from this point the insulator would usually be punctured, while slightly farther away no damage would be done. At the time when the lightning struck the line, the circuit would be short circuited, undoubtedly at the point where it struck. In the case of a steel tower line this would probably cause the shutting off of current before enough time has elapsed to burn off the cables.

Peter Junkersfeld: Mr. Mershon's statement that cost of the transmission line is everything, cannot, it seems, be generally accepted without some qualification. If the owners or managers of the line are interested simply in receiving and delivering power without much restriction or responsibility, the statement might hold. In that case, however, it is only a temporary or perhaps expedient commercial organization, because for ultimate and permanent success we must consider everything all along the various steps from prime mover to the individual consumer.

" Reliability of service " is a term that must be used relatively and usually should be the first consideration, the second being the securing of such reliability for the lowest permanent annual expenditure. This reliability of service is always extremely important. In large cities even with the principal high-pressure transmission underground, this represents a comparatively small part of the total investment in the central station system, and it would seem unwise even for some considerable difference in total cost of high-pressure transmission to take chances with the particular part of the central station system which represents perhaps the greatest responsibility and least annual expenditure per unit of output.

Similarly in the New York Central's present undertaking, the cost of high pressure transmission must be small compared to the total when we consider car equipment, track construction, power and substations, and so on. For reliability let us

compare a duplicate overhead line, six wires on the same set of poles, with a duplicate underground line both in same group of conduit, assuming best construction in each case. In both cases the conductors are heavy enough so that loss of one line will not interrupt the service. Assume now that probability of breakdown in insulation of conductors is nearly equal in the overhead and underground construction, the probability of external injury of all possible kinds is very much greater with the overhead lines. In event of serious short circuit on one line, the probability of both lines being disabled, resulting in a total shut-down of lines, would seem greater with overhead construction, as the two overhead lines on same pole cannot be isolated, while the underground lines can. Experience and observation would indicate that ordinarily with transmission at 11 000 volts, good underground construction would be much more reliable.

In the question of overhead and underground transmission for the particular case of the New York Central, it is probable that there were a number of unusual conditions not generally known. The estimated cost of underground being seven or eight times that of overhead construction, indicates at least one very unusual condition. The annual expenditures, however, on account of transmission lines operation and maintenance, would not be in the same proportion.

President Arnold: Mr. Benezett Williams has requested that the speaker ask this question:

"What would be the effect on the permissible voltage by the protection of the insulators and cross-arms from rain, snow and sleet; that is, how much above 60 000 volts could the pressure be carried?"

The general question is, what kind of protection should the insulators and cross-arms have from rain, snow, and sleet?

F. A. C. Perrine: The speaker wishes to present a proposed construction for discussion; this construction is designed for a 350-mile, 80 000-volt line. On investigating it was found that a 14 by 14 insulator was small enough for 60 000 volts, but it was a question whether any reasonable-sized insulators for use out of doors could be made for 80 000 volts. Furthermore, it was found that with a duplicate three-phase line, if one line was out of service for repair the regulation of a single line would be so bad that the service could not be maintained. In other words, in trying to get along with half the copper the regulation would be too bad to give any kind of service. Consequently a system was proposed involving the erection on a tower of a house about ten feet square with four wires on insulators in separate compartments each being five feet square and ten feet long, the idea being to put the insulators in an enclosed house having four wires all told; three wires being in service at any one time, the other wire being out of service for cleaning insulators and for repair. In that way enough metal

could be concentrated on three wires to ensure regulation. In addition the tower was to be provided every 10 miles with a switching station, so the service of any one wire could be switched on any of the four.

In regard to the covering of insulators, the Kontenric Company in British Columbia has built a line with a pent-house over each insulator but from this they have not derived any very great advantage, for while the pent-house protects the insulators against rain or snow it does not protect them against dust and fog; the combination of dust and fog makes mud, producing the worst possible conditions. In estimating this line, 18 000 volts were figured on.

H. C. Wirt: Will President Arnold say whether the New York Central lines are to be operated with the Y connection grounded? There seems to be a difference of opinion in reference to the advantage of operating in this manner.

President Arnold: No; it is not intended to run it under abnormal conditions; provision is made in the power-houses and sub-stations for grounding whenever the engineers see fit to use the ground wire.

N. J. Neall: Dr. Perrine has brought out very justly the advantages shown by Mr. Blckwell's paper, and moreover the discussion has brought out the fact of a cost that is prohibitive; but it seems that in addition to what has been said as to the advantages electrically, it is not out of the question from a financial standpoint. One matter seems to have been given undue emphasis; that is, the lightning protection. Last year at Niagara we were discussing the advantage the barbed-wire or the ground-wire had over the transmission, that it was a good thing to take off some of the static discharges. You must remember that when you have a climatic disturbance you have an electrostatic disturbance, and an electromagnetic disturbance. The steel tower, and for that matter the barbed-wire protector, does not in any degree relieve us from having protection in the stations. And the electrostatic can be taken to some extent by the entire line, but only incidentally. The best protective apparatus to-day provides for the discharge of this disturbance as well as the electromagnetic. We cannot consider the steel tower as having anything more than an incidental advantage, but they are better than wooden poles because they will absorb from the atmosphere some of the static disturbance.

F. O. Blackwell: There is another thing in connection with steel-tower construction. The towers can generally be located on high ground, so that the maximum sag will occur over the low ground between towers. A tower would naturally be located at the highest point—on every hill which is passed over—these are the points which would naturally be struck by lightning, and the towers, if especially provided with points projecting above the line, will take a lightning charge without

affecting the system. Wherever there is a sudden change in altitude, or other conditions which cause lightning phenomena at certain points, there should be lightning-arresters connected to the circuits which will discharge them to ground.

N. J. NEALL: In consideration of the relatively great distance between cloud and line, the addition of lightning-rods to metal towers would probably not be as effective as Mr. Blackwell suggests, and hence for any direct strokes the metal towers should be able to attract and discharge these disturbances as well as if equipped with lightning-rods.

H. C. WIRT: Reports received from a few plants where ground-wires are used indicate that such wires prevent the shattering of the wooden poles and they also assist to protect the apparatus at stations and sub-stations. If the interruptions due to shattering of poles are frequent, it may be necessary to use ground-wires.

N. J. NEALL: Is the case referred to by Mr. Wirt regarded by him as general or special, because there have been plants where transmission lines have had their poles shattered and the continuity of service not disturbed. Any questions regarding overhead grounded wires are meant solely to bring out their value, not to disparage their use. If lightning has shattered poles and disturbed the service then any protection of the pole to eliminate this is indeed valuable. It seems too early to decide the worth of overhead grounded wires, and we must certainly wait until those who have had the courage to install this system and investigate its behavior report their observations; and even then to be of permanent value these observations must cover a wide geographical area and have lasted for more than one lightning season. So far these observations have been special. If we should take up the metal tower, then overhead grounded wires would probably not be used.

S. B. STORER: One of the speakers said in referring to the use of barbed-wire that he frequently obtained an extra high pressure between any two transmission lines. Now if a barbed-wire is added to the transmission line it seems to the speaker that the trouble is increased about one-third, because the same pressure might obtain between the grounded wire or between the barbed wire and the transmission wires that would obtain between any of the transmission wires.

H. C. WIRT:—Theory or laboratory tests should not be relied upon wholly in the design of lightning-arresters. We will have to work with the lines themselves and make extensive trials on any protective device that may be proposed. Recent examination of transformers that have burned out has shown that a very high pressure has existed from line to line. Attention is called to a photograph of a connection board printed in the speaker's paper. The tension necessary to make an arc go across the terminals was 42 000 volts, and the working

pressure was 2000 volts. Too much attention has been given in the design of lightning-arresters to provide an easy path to ground and too little to prevent a rise of pressure between line and line.

In low-pressure work we started with transformers using insulation between primary and secondary that would withstand two or three times the working pressure. We now have to insulate our transformers to withstand five times the working pressure of 2000 volts. With these modern transformers we find that the burn-outs due to lightning effects are from line to line and rarely from line to ground. With high-pressure transmission lines it would seem to be necessary to provide a path from line to line as well as from line to ground so as to prevent the lightning current making its own path through expensive apparatus.

In many cases reactive coils were used for protection. It is possible to have an electromagnetic effect in the line wires; that is, upon a heavy stroke of lightning passing to ground high-pressure currents are created in the transmission system.

R. F. HAYWARD (*by letter*): Since the commencement of transmission work in Utah the writer has maintained the opinion that structural strength and stability are the first requisites for transmission lines. Every year's experience has strengthened this opinion. There are now 500 miles of transmission pole-line in Utah, and experience has abundantly proved that the line which is mechanically strongest gives the best service.

Glass insulators are not mechanically strong enough, nor will they stand the continued stress of heat and cold. Wooden pins should not form part of a strong line. Iron pins have been used on all the corners of the Pioneer line between Ogden and Salt Lake, and there has been no failure on their account in seven years. Porcelain insulators have stood the test of strength thoroughly well. Where properly designed and made, they do not check or break except when shot, and then they only chip instead of flying to pieces like glass. In only two or three instances have short circuits been caused in the Ogden-Salt Lake line by insulators broken by a rifle shot, out of thousands which have been chipped by bullets.

On a transmission line, the failure of one pole or one insulator may cause an interruption of service and therefore the factor of safety should be very large. A line designed for 50 000 volts can be depended upon for 30 000 volts. If a transmission line cannot stand the cost of an expensive porcelain insulator there can be no profit in building it. There is little excuse for interference from trees, but it is more difficult than might be supposed to get rid of trees in settled districts. In eight years' service on the Ogden line the greatest amount of trouble has been caused by burning of poles from brush fires. Careful patrolling has kept the interruptions from this cause down to a very small amount, but on one occasion 15 poles

were burnt off in a sage-brush fire. In a few cases poles have been splintered and insulators shattered by direct lightning strokes. Except in these instances no breakdown of the line itself can be directly traced to lightning.

There have been many interruptions caused by wires or sticks thrown over the lines; a few by birds, and one by a wild-cat. Once only has a pole been blown down, while once the whole superstructure of a box car was blown from a train into the wires.

In the inter-mountain region wooden poles have a life of not more than ten years; many last only five years. It has been found that salt is the best preservative for the butts of poles, but if the butt is made to last ten years the upper part of a cedar pole will check and become so brittle that its useful life is gone in that time.

The writer in 1903 constructed a pole-line for the Utah Sugar Co. from their power-house on the Bear River to the Utah Light and Railway Company's power-house at Ogden, a distance of 45 miles. The line was designed for 40 000 volts, and is operated at 28 000. It is located at the base of the Wasatch range, just above cultivated ground, but within a few hundred yards of a good county road. The location was costly as regards pole construction, but was necessary in order to avoid trees. The line consists of 40-foot cedar poles with cross-arms. The wires are spaced on a six-foot triangle. The upper cross-arm is short and the insulator is placed on alternate sides of consecutive poles. This arrangement avoids the bad practice of placing a pin on the top of a pole. The lower cross-arm is heavily braced and the cross-arms are strengthened and prevented from splitting by ⅛-in. steel plates held together by carriage bolts. Poles are spaced 44 to the mile. The line wire is No. 0, soft-drawn, solid copper. The insulators are three-part Locke brown porcelain. The upper part is 11-in. diameter, and was tested to 40 000 volts. The middle part was tested to 30 000 volts, and the lower to 50 000 volts. The pin is of cast iron with a collar 3½-in. diameter and a ⅝-in. steel bolt cast into the shank. It is cemented into the insulator with neat Portland cement. The pins and insulators complete weigh 20 lb. each and cost nearly $2.00 in place on the pole. They are heavy and expensive, but they are strong and make a splendid insulator for a heavy line.

In stringing wires half a mile of wire was stretched at a time, and the writer has repeatedly seen a single insulator stand the whole strain without any trouble. There are three long spans on this line, two of 250 feet and one of 450 feet. Solid No. 0 was used for these spans, and 15 feet sag allowed. The wires were supported by three insulators at each end, set in a special iron fixture. The whole strain of the span is taken by these insulators. All corner strains are taken by single insulators and they are strong enough to stand them. The

whole line was built for mechanical strength and so far it has given no trouble. Some 30 or 40 of these insulators have been in use through the past winter on outdoor 40 000-volt air-switches and have shown no sign of failure. The insulators are not expensive to repair, as the upper part when broken can be cracked off and a new part cemented in its place; the pin and the rest of the insulator are used over again.

This pole-line cost $2000 per mile, and has probably as much steel and iron in its construction as can be used on any wooden line. The next important line in Utah will undoubtedly be entirely steel supported, for a careful comparison of costs shows that the Bear River line, just described, could have been built just as cheaply with steel towers as with poles.

The writer believes that a single line of steel towers set 500 feet apart carrying two circuits of copper wire, spaced on six-foot triangles, will be much cheaper, both in first cost and maintenance, and freer from interruption and safer for repair work than two separate wooden pole lines.

It may be argued that if a wire from any cause drops on the structure it will make a dead short circuit. It will, but the wire will be burnt off in an instant and in a properly laid out and operated plant the trouble will be located and the section isolated without delay.

It would be interesting to get figures on the cost of erection of the steel towers, assuming labor at $1.50 per day, teams at $3.50 per day, and average length of haul four miles. The writer is not in favor of using aluminum cable. It is cheaper and lighter than copper, but it lacks the strength and may be worth very much less per pound in a few years, whereas copper is not liable to depreciate much in value.

A. S. Hatch (*by letter*): On page 310 it is assumed that the steel towers act as lightning-arresters. The writer cannot agree with the statement unless the tower is grounded in permanently moist earth. In testing the street lighting circuits for grounds or opens, it is found that the towers are not generally grounded in dry weather, being grounded but a few days after a storm. As a storm usually follows dry weather, at least before the rain has had time to penetrate any distance into the ground, the towers may be fairly well insulated by the dry earth. There have been several instances where lightning has struck a tower and, following a guy-wire to the wooden stub, has splintered it in passing to earth rather than follow the tower. In one case, lightning struck a tower and puncturing the lamp insulator discharged through the circuit which was grounded in the station. This experience, together with the statement made during discussion that the steel towers were usually located on high points of ground, emphasize the importance of grounding the towers thoroughly.

A paper presented at the 188th Meeting of the American Institute of Electrical Engineers, Chicago, June 21-22, 1904.

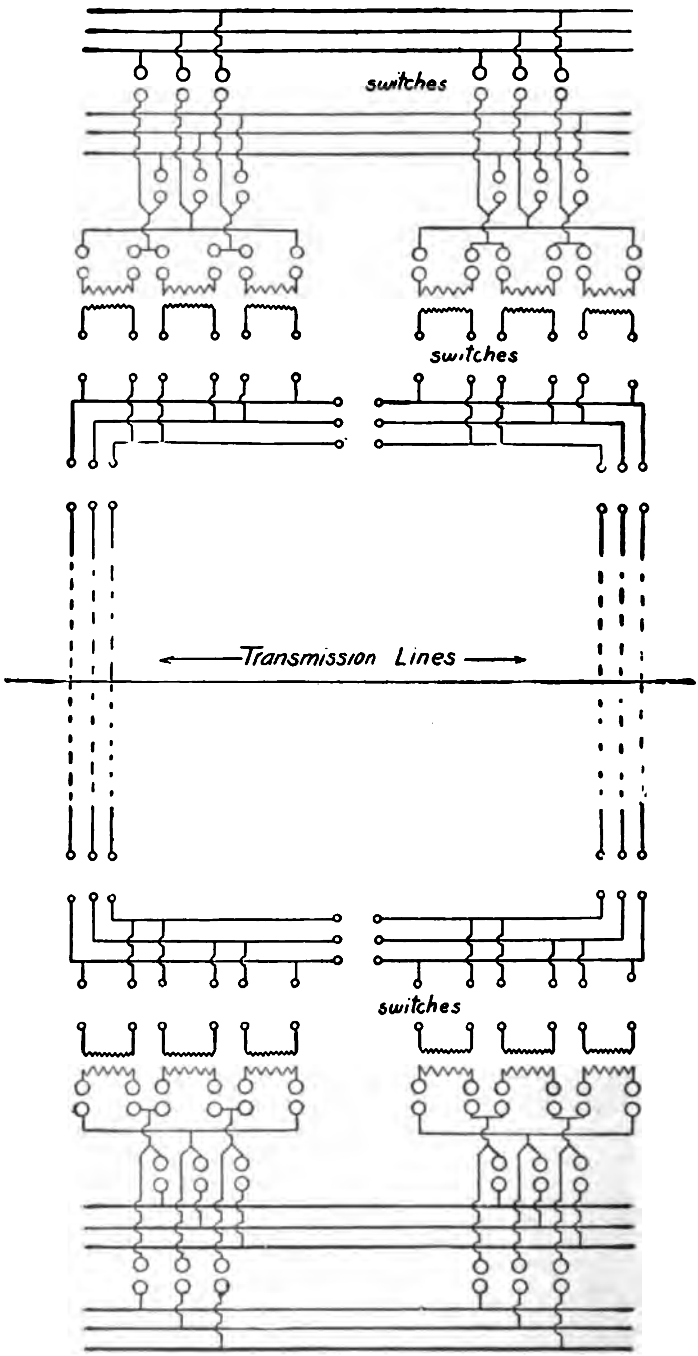
CONDITIONS FOR CONTINUOUS SERVICE OVER LINES OPERATED IN PARALLEL.

BY M. H. GERRY, JR.

In order to maintain a continuous service, nearly all of the more important transmission systems have installed two or more pole lines, each carrying one or more circuits. As a rule the circuits are operated in parallel but are so arranged that at least one of them may be entirely disconnected without interrupting the delivery of energy.

Two sets of conditions are met with in practice: first, normal operating conditions; secondly, accidental conditions. It is possible by design to provide for the first, and, in the main, for the second. The normal operating conditions include inspection, repairs, and additions to the circuits. But little work can be done on high-pressure circuits while in service, and it follows that adequate switching devices must be provided such that any circuit may be disconnected without an interruption of the service.

Both the air-break type of switch and the oil-switch are now available for pressures to 60 000 volts, and may be installed in various ways to obtain the desired results. They may be operated either automatically or manually. There are in use several systems of switching transmission circuits in parallel. Some arrangements provide for connecting only the low-pressure side of the transformers; others only the high-pressure side, and still others provide for the connecting of both the high- and the low-pressure sides in multiple. An arrangement of connections for two transmission circuits in parallel is shown in the accompanying diagram.


switches
switches
Transmission Lines
switches

This system may be elaborated by adding group-switches on one or both sides of the transformers. If more than two circuits, or more than two banks of transformers be employed, various devices are resorted to for providing the required flexibility. Practice in this last connection has taken the direction of sectionalized bus-bars, with some form of group switching. In addition to the switching devices at either end, it is desirable on long lines to install sectionalizing and paralleling switches so arranged that a section of a transmission circuit may be entirely isolated and the remainder continue in parallel with the other circuits. The switches for this purpose are usually mounted on the poles and are operated manually. It is probable that the practice of sectionalizing long transmission lines will be extended in future and that improved switching apparatus will be employed for this purpose.

In addition to normal operation, the accidental conditions which may arise and affect the continuity of the service should be anticipated and provided for. These conditions, whatever may be their primary cause, usually result in an open circuit, a short circuit, or a grounding of the conductors. Whenever one of these occurs it is essential that the entire circuit, or at least the defective section, be immediately isolated from the other circuits of the system. This may be accomplished either by automatic devices or by the attendants. The automatic methods, on account of the time-element involved, are undoubtedly superior, but the apparatus should be of thoroughly reliable construction and should be tested frequently if the best results are to be obtained. The best practice calls for circuit switches controlled automatically by means of time-limit overload relays at the generating end, and similar switches controlled by time-limit reverse-current relays at the receiving end. These devices properly installed will effectually isolate a transmission circuit in case of trouble, but other conditions must also be considered if the service is to be uninterrupted. Whenever a parallel circuit is disconnected it disturbs the entire system and especially affects the electrical pressure. A long transmission circuit represents a considerable capacity, inductance, and resistance, and when this is removed or placed in parallel to other circuits, it becomes necessary to readjust the pressure. This is usually done by the attendants at the generating station but a reliable automatic device would be of value for this purpose if designed to meet all the requirements of transmission service.

A considerable change in pressure at the receiving end of the line may result in an interruption if induction motors or synchronous apparatus be operated by the current. The greater the number of circuits in parallel, the smaller the amount of disturbance produced by removing a single circuit. Many of the better high-pressure transmissions depend, however, upon two lines of one circuit each, and in case of accidental difficulty with one of the circuits the entire load is carried temporarily on the other line. By a proper design this may be successfully accomplished, and even in the case where one of the circuits is suddenly isolated by automatic devices the variation of pressure may be kept within such limits that there will be no interference with the service.

The reliability of high-pressure and long-distance transmission has been thoroughly demonstrated, and it has been shown by actual results that a continuous service can be maintained for indefinite periods by the use of multiple lines and proper appliances.

Discussion on "Conditions for Continuous Service over Lines Operated in Parallel."

Ralph D. Mershon: There is one point which the speaker would like to have taken up, because of its bearing upon a previous discussion at Niagara Falls. The speaker refers to reverse-relay devices; they are interesting things to talk about, but does anyone know of a reverse-relay device that will work under all conditions?

P. H. Thomas (by letter): Absolutely continuous service may be realized in theory and ultimately will undoubtedly be closely approached in practice. At the present time, however, no such perfect devices are available.

The usual arrangement of overload circuit-breakers at the generator end of two transmission lines in parallel and reverse-current relay circuit-breakers at the other ends does not operate properly in all cases when there are generators at both ends of the line. A theoretically satisfactory arrangement can be constructed, however, which will open the right line at both ends in all cases of short circuits by operating at all points at which the lines are paralleled, the relays controlling the circuit-breakers jointly from current transformers connected in the two lines. These currents must be so directed that during an equal division of load between the lines (or division in any desired proportion if so desired) the influence of one line shall just neutralize the influence of the other line. When with this arrangement current is reversed in one of the transmission lines, the influence of two lines is in the same direction in the relay and can be made to open the defective line.

Another method appears to the writer to have a number of advantages. In endeavoring to maintain continuous service with apparatus now available, the system having duplicate parts all through may be operated as two systems entirely independent electrically, each so arranged as to carry approximately one-half load. Each of these systems should of course extend into all important sub-stations. In case of trouble to one line causing a drop of pressure, half of the load of the system will be dropped. Immediately this should be thrown to the other system, which must of course be able to carry the double load for a short time. If the attendants are properly instructed this may be done without special orders from headquarters, thus avoiding a very important loss of time. All parts of the dead system which are uninjured may then be immediately paralleled with the live system, enabling it to carry the full load easily.

A paper presented at the 188th Meeting of the American Institute of Electrical Engineers, Chicago, June 21-22, 1904.

THE USE OF GROUND-SHIELDS IN TRANSFORMERS.

BY J. S. PECK.

In any transformer there is a possibility that the high-pressure winding may become metallically connected to the low-pressure winding through failure of the insulation between these windings, so that if the low-pressure winding is not connected to ground it may be raised to a high potential above the earth. Under these conditions a person coming in contact with the low-pressure circuit may receive a dangerous shock, while the apparatus connected to this circuit is subjected to undue strains. If, however, the low-pressure winding is connected to ground, the maximum difference of potential which can exist between any part of it and ground is that which is established between the grounded point and that portion of the winding farthest removed, electrically, from the ground.

The ground-shield is a metallic sheet so placed between the high- and low-pressure windings of a transformer that the high pressure cannot break through to the low pressure without first going to ground. The ground-shield should be made preferably of copper, of a thickness of approximately 1/32 in., though it may be of any conducting material, and of practically any thickness desired. A convenient arrangement is to connect the ground-shield to the core of the transformer, which is grounded directly, or through the case. It is obvious that since the ground-shield surrounds the magnetic circuit it must not form a complete turn, and for this reason it is cut through in one place and the joint insulated.

While upon first thought the use of a ground-shield would appear to eliminate entirely the possibility of an abnormal pressure existing between low-pressure winding and ground,

there are, nevertheless, ways in which it may fail in accomplishing its purpose, and there are numerous practical difficulties in its use, particularly in large high-pressure transformers.

Some of the objections to the ground-shield are:

1. It does not prevent the possibility of an abnormally high pressure existing between low-pressure winding and ground, due to a connection between high- and low-pressure leads inside the case, or in the wiring exterior to the transformer.

2. The ground-shield must be of thin material. With transformers of large size where enormous current may flow in case of a short circuit, it is possible that a portion of the shield may be burned away or that the connection between it and the ground connection may be burned off, thus leaving the high- and low-pressure windings connected, but insulated from ground.

3. The introduction of the ground-shield into a transformer increases its cost, or lowers its efficiency, or both; for the same amount of insulation must be placed between the high-pressure winding and the ground-shield as is ordinarily placed between high- and low-pressure windings; and in addition the ground-shield must be insulated from the low-pressure winding.

4. In transformers there is a leakage magnetic field between high- and low-pressure coils. In that portion of the coils outside the iron this leakage field cuts through the ground-shield, producing eddy currents which may greatly increase the transformer losses. This is particularly true on high-pressure transformers where it is necessary for insulation purposes to make a difference in the lengths of the coils. On such transformers it is necessary to use very thin sheet-metal for the shield, and to slit it at the ends into a number of narrow strips, which are insulated from each other, except at one point.

Conclusions.—Since the ground-shield does not afford absolute protection, and as it increases the cost or reduces the efficiency of the transformer, and on account of the mechanical and electrical difficulties involved in its use, it would seem that for large high-pressure transformers the ground-shield is a theoretical, rather than a practical, means of protection.

It is believed that the grounding of the low-pressure winding at the neutral point is a safer, more practical, and cheaper method of protection than is the use of the ground-shield.

Discussion on "The Use of Ground-Shields in Transformers."

Ralph D. Mershon: Undoubtedly, if grounding the neutral of a low-pressure winding does not protect, protection will not be obtained by the use of ground-shields. It seems to the speaker that it is not safe to install a high-pressure transmission system, feeding a city distributing system, without either making use of ground-shields or grounding the neutral of low-pressure windings. Aside from the question of a cross between the high- and low-pressure circuits, it is possible, with everything in good condition, to have electrostatic effects of high pressure on the low-pressure windings, high enough to damage insulators and endanger life. It seems therefore that it is rather unwise to install transformers feeding distributing systems without using one of these means of protection. In some cases the expedient of using spark-gaps between the low-pressure windings and ground is resorted to, and in some cases between the neutral and the ground instead of grounding the neutral. But these spark-gaps are generally the cause of more or less trouble; it is the speaker's opinion that it is much better to ground the neutral permanently.

H. C. Wirt: Transformers having ground-shields were used to a limited extent in this country at a time when the National Board of Fire Underwriters would not permit grounding the secondary. Now that grounding the secondary is permitted, there seems to be no good reason why transformers with ground-shields should be used.

C. E. Skinner (by letter): In specifying the use of ground-shields between the high-pressure and low-pressure windings in transformers, engineers seek to prevent any possibility of an electrical connection between these windings. The question to be considered is, therefore, whether or not this result can be accomplished.

In the writer's opinion, ground-shields are very undesirable from a constructional standpoint; they do not necessarily accomplish the result for which they are used, and they increase the cost of transformers in which they are used. The writer agrees that the grounding of the low-pressure winding at the neutral point is a safer, more practical, and cheaper method of protection than is the use of the ground-shield. This method gives almost absolute safety, while the use of the ground-shield is at best a doubtful expedient.

P. H. Thomas (by letter): Mr. Peck has hardly emphasized sufficiently the objections to the use of ground-shields in large high-pressure transformers. That a very efficient protection against the raising of the pressure of the low-pressure winding of transformers, due to a certain class of breakdown, is secured, cannot be denied, but the incidental difficulties and opportunities for trouble introduced through the use of ground-shields far

outweigh its advantages, when protection can be so simply obtained otherwise.

The writer fully agrees with Mr. Peck's conclusions, but wishes to bring out one point: when the grounding of the neutral point of the system is relied upon for protection, there is one weak point. From the nature of the case, the connection between high pressure and low pressure, when occurring on wiring or at the leads of transformers, will be of the nature of a static discharge, also the low-pressure winding of the transformer constitutes a choke-coil between the source of the disturbance and the grounded point; as a result there will be a short-circuit strain impressed upon it of a very severe nature, which may easily cause a breakdown of insulation. This may be avoided by using lightning-arresters as discharge gaps on the leads of the low-pressure winding. This method will not be effective where the connection between high-pressure and low-pressure systems occurs at an intermediate point in the winding of the transformer. Since in this case the transformer is already injured, this fact will not be of such serious consequence.

W. L. Waters (by letter): A ground-shield undoubtedly affords some protection, but such protection can be obtained in a much simpler and more reliable way by grounding the low-pressure side of the transformer, or by means of some automatic grounding device, such as the Cardew. Considering the question from all points, the writer agrees with Mr. Peck, that the doubtful protection afforded by the ground-shield is obtained at far too high a cost, and that at the present time a ground-shield would be more suitably placed in a historical museum than in a power transformer.

A paper presented at the 188th Meeting of the American Institute of Electrical Engineers, Chicago, June 21-22, 1904.

THE PROTECTION OF HIGH-PRESSURE TRANSMISSION LINES FROM STATIC DISCHARGES.

BY H. C. WIRT.

The various devices for the protection of transmission lines from lightning and other static stresses, made by the leading electric companies, are constantly modified, and it is apparent that improvement in this class of apparatus is needed. The best way to develop such devices is to make a careful examination of the transmission lines and of apparatus that may have been damaged by such high-pressure discharges. It is to be hoped that the following comments on various devices now in use will be of interest, and will bring out discussion of their operation.

Ground-Wires.—Overhead ground-wires have been used in several transmission plants. It is evident that if efficient protection can be secured at the power-house and sub-stations, it is superfluous to use such an overhead wire. If a ground-wire be used, it must be large enough not to break and of material that will stand corrosion; a suitable wire will cost almost as much as an additional transmission wire.

A certain power transmission plant, having three power-houses and seven sub-stations, operating 90 miles of overhead transmission lines at 40 000 volts, has protected the greater part of its transmission system by No. 4 galvanized iron wire placed at the top of the poles, half the length being barbed wire, the other half plain wire,—the wire being grounded at every fifth pole. This wire was installed about 14 months ago; before that time many of the poles had been shattered by lightning, but since then no pole has been damaged, but some apparatus has suffered from lightning, the arc jumping from the trans-

former lead above the oil, in all cases. If lightning-arresters had been placed at all the stations, and no overhead wire used, there would probably have been less damage to apparatus, but the poles would have been shattered. It is not at present the custom to use lightning-arresters on transmission lines, and it is not known whether poles can be protected in any other way than by an overhead ground-wire. It would be of interest to have data upon the frequency of interruption of service of transmission lines on account of poles being damaged by lightning. My opinion at present is that a transmission line can be protected from lightning discharges by suitable apparatus placed in the stations, and that it is not necessary to use ground wires; but an exception will probably have to be made in cases where poles are shattered with great frequency.

Another installation, operating at 25 000 volts, uses lightning-arresters at stations and sub-stations, with reactive coils, constructed to break down at 50 per cent. above the working pressure, and with a resistance in the ground connection. The arresters have a series of gaps, and are equipped with the " multiplex connection," giving a minimum breakdown distance between line and line. Prior to the installation of this equipment, there was frequent loss of apparatus at the stations, but since, no apparatus has failed on account of lightning, although there have been many severe storms. The management of this plant had begun to equip the transmission lines with a ground-wire, but has decided not to proceed with this plan.

We have in these two cases entirely opposite methods of protecting lines. In one case, the management is so well satisfied with ground-wires that lightning-arresters will not be used; in the second case, the management is so well satisfied with lightning-arresters that ground-wires will not be used. These two plants are in country very similar in its physical characteristics, and are only a few hundred miles apart.

Experience with apparatus damaged by lightning proves that it is as important to provide an easy path for the lightning discharge from line to line as from line to ground. Up to the present, the principal idea in designing a lightning-arrester has been to provide a good path to ground; they have frequently required twice as great a pressure to break down the gap space from line to line as from line to ground. Recently a new type has been suggested called the " multiplex connection," in which a shorter path is provided from line to line, requiring practically

the same breakdown pressure as from line to ground. It is believed that this type will afford additional safety. The photograph herewith shows a particular case in which lightning passing from line to line, jumped across from one terminal to the other of a porcelain primary connection board; to jump this space required 42 000 volts.

Reactive Coils.—Much difference of opinion has existed among engineers on the value of reactive coils, in connection with lightning-arresters. Some recent tests made with the best types of lightning-arresters show that the arresters did not protect the apparatus until reactive coils were used; it seems now that there can be no question that reactive coils are effective, and therefore they should always be used. Although much has been written upon lightning-arresters, there

is little available information upon the relative pressure suitable for the spark-gap; it is difficult to determine just how near to the pressure of the generator a spark-gap can be adjusted without danger of flashing over. When apparatus has burned out, it is possible either to increase the insulation resistance or to decrease the spark-gap distance. Many arresters are now supplied, adjusted for a breakdown pressure only 50% greater than the generator pressure; it can be determined only by experience whether it is feasible to set arresters nearer the generator pressure than this; generators are in many cases insulated to stand only 50% increase above the working pressure, and in this case there is no difference between the breakdown pressure of the insulation and the spark-gap; but the insulation of the machine stands a one-minute test and the static stresses exist only momentarily, which is undoubtedly

the reason that apparatus has not burned out more frequently. Present experience indicates that apparatus, to be safe, should stand an insulation test of 100% greater than rated pressure for one minute; such apparatus may have to be insulated for higher pressure than the present INSTITUTE standard, as it is extremely difficult to protect apparatus unless it will stand the double-pressure test.

Experiments have shown that very high pressures exist momentarily between the outside turns of the coils of a transformer at the moments when it is switched into or out of circuit. Transformers insulated for only 1000 volts per turn will withstand these very high pressures momentarily; as the best modern construction of transformers provides for reenforcing the insulation in the outside turns, thus providing a larger factor of safety, it is a question where the additional protection against breakdown of the outside turns should be provided; a rise of temperature on switching transformers has been noticed in some installations, which is attributed to capacity and reactance, producing resonance, and it has become the practice to provide special means to obviate any rise of pressure due to these causes; such apparatus is known as a "static-arrester." It is necessary only to provide a circuit having a moderate current capacity in order to relieve the line of high pressure, due to these causes.

Discussion on "The Protection of High-Pressure Transmission Lines from Static Discharges."

J. S. Peck: Mr. Wirt says: "Many arresters now are supplied adjusted for a breakdown pressure only 50% greater than the generator pressure." While this adjustment is a measure of the breakdown pressure of the arrester at the generator frequency, it does not necessarily measure the pressure at which the arrester will break down under an extremely rapid change of potential; that is, static discharge. All high-pressure arresters now consist of one or more air-gaps in series with a resistance connected between the line-wire and ground.

Tests have recently been made on a number of these arresters to determine the pressure at which they would break down under two conditions: first, with a current of low frequency, such as is developed by the ordinary alternating-current generator; and secondly, by suddenly discharging a condenser through the arrester. It was found that in all cases the pressure required to break down the arrester under the condenser discharge was very much higher than was required at the generator frequency. With the condenser discharge the pressure was measured by means of a spark-gap shunted around the arrester. By placing the spark-gap around different portions of the arrester, it was found that the greater part of the excess pressure required to break down the arrester under the condenser discharge, was taken up by the series resistance.

It is obvious that if a highly inductive resistance were connected in series with the air-gap, the discharge of a condenser through it would be greatly impeded; and it appears that even the straight carbon-rod resistance offers a considerable amount of impedance to the discharge of a condenser. For this reason the speaker thinks that a statement regarding the breakdown pressure of an arrester under generator frequency is of practically no value as a measure of its protective power against lightning discharges.

Ralph D. Mershon: It is gratifying indeed to know the result of the experiment just cited by Mr. Peck. The writer thinks the result was probably due to the fact that the "non-inductive resistance" was non-inductive in name only.

The question of the accurate adjustment of the striking pressure of arresters is relatively non-important. We do not so much care whether the arresters will discharge at 50 per cent. above the generator pressure, or at 100 per cent. above it, as we do that when they do discharge they will allow to pass sufficient current to keep the pressure of the discharge down to a safe figure and still prevent the generator current from continuing and holding an arc after the discharge has ceased.

Another matter often overlooked in the case of metal cylinder lightning-arresters—a matter which sometimes gives considerable trouble—is the amount of power that they take on

discharge. A 2000-volt arrester with a given number of gaps will take on discharge a given amount of generator current. If on 50 000 volts the number of gaps is increased in proportion to the pressure, the current will be the same on discharge, but the power taken will be about 25 times as great; the result is that if there is a great amount of load on the system there is not enough power left for anything else on the circuit while the lightning-arrester is operating. This condition is especially bad for the operation of synchronous apparatus.

N. J. NEALL: The speaker wishes to take exception to the conclusions drawn by Mr. Wirt—that experience with apparatus damaged by lightning proves that it is as important to provide an easy path for the lightning discharge from line to line as from line to ground.

If we take into account the great distances between the cloud and the line during a lightning disturbance, and the relatively small distances between wires, then, relatively, all wires of any transmission line receive their disturbances as if they were formed of one wire; and it is therefore difficult to see how any difference of potential from this cause could exist between any two wires. It follows that the assumption made—of the necessity for a discharge between wires—does not hold theoretically.

The study and development of protective apparatus during the last eight years emphasize very strongly that certain phenomena occur repeatedly and can be overcome. Generally speaking, if nothing is destroyed in a station equipped with protective apparatus, or if the troubles are comparatively few, the protective apparatus is very highly thought of, although it might turn out that the arresters were really not protecting, and other causes were accountable for relief from lightning disturbances. An excellent plan is to have station operators or line operators record the action of the protective apparatus on their systems, just as they would record the operation of their generators or transformers or any other apparatus which can be metered. A device for this purpose has been suggested, that of using a slip of paper in some of the arrester gaps which would be punctured by discharges. If these papers are removed frequently and systematically doubtless much of the phenomena which we have been studying would have further evidence to substantiate our theories. It is also likely that many troubles would be brought to light that are far more injurious to the normal operation of the line than are lightning disturbances.

Another difficulty is the close setting of spark-gaps to any given pressure. Those who have worked with spark-gaps and spark-gap material know that it is extremely difficult to make measurements and repeat them within five per cent. of the pressure which can be estimated by the ratio of turns. Moreover, it does not seem of such importance in lightning-ar-

resters that we should set our gaps so closely, because if regular apparatus must stand 50% rise certainly any spark-gap can be set to meet such requirement.

F. O. Blackwell: Lightning occurs at irregular intervals and in different forms. The kind of arrester which would be best in one lightning storm might be of no value in another. In general, the best we can do is to have a weak point in the system which will allow the lightning to pass through without damaging the machinery. The most primitive form of lightning-arrester, which consists of a grounded pail of water and a wire from the water to the line, furnishing a constant leak to ground, is very effective.

H. C. Wirt: A type of lightning-arrester used in Switzerland and Italy consists of a jet of water turned on the line, so that the line will be discharged through the stream of water. Neither the water-stream arrester nor the horn arrester will take a sufficiently large discharge to relieve the line properly. The principal difference between these arresters and those of American design is in the number of gaps employed. The water-stream arrester with a single gap could be used but the water would have to be of high resistance to prevent an arc holding.

We have not tried either of these lightning-arresters but we intend to do so. The question of the amount of current that an arrester should be designed to take is undetermined. If the resistance used in the arrester is low the current that would follow after a lightning discharge may be large enough to shut down the plant; if the resistance is too high the lines may be only partly relieved and the lightning may then go through some transformer. We should of course consider the lightning-arrester in theory but we should also have extensive tests of arresters under service conditions. The speaker means that no one should decide for or against the use of a ground-wire unless he has been at places where such wires are in use.

R. F. Hayward (by letter): The writer believes that it is the apparatus, not the pole-line which needs protection from lightning. If poles get shattered frequently it may, as is pointed out, be necessary to use a grounded wire, but steel construction would be a better remedy.

The transmission lines in Utah, consisting of 300 miles of 40 000-volt pole-line and 125 miles of 28 000-volt line are situated at the base of the Wasatch range where the thunder-storms almost invariably break. These lines are particularly liable to be affected by lightning, and every thunder-storm manifests itself in some way. It is seldom, however, that poles are struck, though there have been several cases of shattered insulators and splintered poles. With duplicate lines the striking of a pole should cause but a short interruption, and the damage is easily repaired. But if the transformers are damaged a whole station may be temporarily disabled,

and the damage is costly. When a pole-line is struck a wave is set up which finds its vent in a lightning-arrester, breaks itself against a transformer coil or breaks down the coil. If the insulation of the coil stands the shock and there is no lightning-arrester discharge, an arc may form from terminal to case. Experience seems to show that a lightning discharge has the greatest effect on the station nearest to it, but that the horizontal discharge, occurring between clouds and more or less parallel to the lines, produces some of the most severe shocks at lightning-arresters or transformers. In the neighborhood of Salt Lake City it seems that there is a greater tendency to horizontal discharges between clouds than to lightning discharges direct to ground. This is doubtless due to the abrupt rise of the mountains from the level of the valley. There is no doubt that lightning can and does induce very high pressure waves between wires, many instances having occurred in Utah. Protection should therefore be provided against this.

The writer is in doubt about the use of reactive coils, as there are instances which show their value, and others which do not. It seems that a reactive coil to be effective must be pretty large. It has occurred in the writer's experience that a pole has been struck with lightning and at the same instant a discharge has occurred from transformer terminal to case, while there was no discharge over lightning-arresters, although a reactive coil was in circuit.

Instances showing that a transformer coil or the windings of an armature act as a " breakwater " to the passage of high-frequency waves are too numerous to mention. One instance is interesting. One of the 2000-volt circuits supplying Ogden City is lead from the power-house through booster transformers. A severe storm occurred when the boosters were not in circuit and a discharge took place across the collector rings of one of the armatures in the power-house. A few days later a similar storm occurred when the boosters were in circuit and one of them was burnt out.

The writer believes that reactive coils of comparatively cheap construction should be put in to satisfy the conscience of the engineer, but for real protection the money should be spent on the transformer. An 80 000-volt transformer working on a 40 000-volt circuit and protected by a 40 000-volt lightning-arrester ought not to break down. The writer's opinion has changed somewhat during the past year in this matter and he now believes that any reactance coil of large capacity introduces some extra apparatus and additional wiring, whereas the same money spent in the transformers themselves ought to provide sufficient insulation to stand these shocks.

The writer believes that lightning-arresters should be adjusted so that they are near the limit of their own safety; plenty of spare parts should be provided and an occasional burnout

of the lightning-arrester resistance should be accepted as proof that the lightning-arrester is giving some protection. Anyone can put so many gaps and so much resistance in an arrester that it will never burn out, but it does not follow that this arrangement affords any protection.

P. H. Thomas (by letter): Static discharges in high-pressure transmission lines arise from two causes: first, abrupt changes of potential caused by switching or accidents in the transmission system itself; secondly, lightning.

The best protection against the first class, which are certain to be quite numerous, is in providing ample insulation in the design of the plant, not so much in the heavy thicknesses of the solid insulating material, which is exceptionally strong to resist static strain, as in the air distances, oil distances, and surface distances between exposed points. In the opinion of the writer, it is extremely important that these distances be ample. For instance, they should be laid out to stand with certainty double the normal pressure of the system, since probably in very few cases would static pressures exceed this limit, except of course in case of lightning. It is true that pressures of startling magnitude are occasionally reported from transmission plants, but in few cases have the existence of such been clearly proved, and in many cases the reports have proved to be unfounded.

In laying out surface distances and air spaces, it must be remembered that the jumping power of high pressures increases much more rapidly than the pressure itself. Distances should not be doubled for double pressure but a curve of actual tests should be used. It must be remembered as well that surface distances have their insulation strength much deteriorated by a deposit of moisture or of conducting dust, and that some kinds of material, notably hard rubber, may have a gradual deterioration. It must also be noted that the jumping distance over a surface is much affected by the presence near that surface of another conductor at a different pressure. For example, a wire within a bushing, and the presence of such a conductor, in extreme cases may increase by several times the jumping distance of a given pressure. *This fact is very well established and has been given entirely insufficient recognition in laying out surface distances for insulation.* Still another factor weakens the insulation strength of surfaces when subject to static discharges; namely, the fact that for an abrupt change of pressure a considerable quantity of electricity must flow at the time of the application of strain to charge up the surface of the insulation near the charged conductor, and this flow of current momentarily weakens the total insulation strength of the surface.

It appears to the writer that since a great mass of data with regard to the effect of ground-wires or other devices on the elimination of troubles due to lightning is required to eliminate

the effect of conditions other than those being studied, that little can be gained from the consideration of one or two cases of ground-wires, and that all our accurate data furnish an insufficient basis for conclusions at the present time. It seems unlikely that even though the grounded wires may be proved to have protective effect, as they undoubtedly do, they will ever be of general use, in view of the mechanical and electrical difficulties and expense involved. As Doctor Perrine has stated, there is a tendency where ground-wires are brought near to high-pressure conductors, for current to be set up in the ground-wires, causing more or less energy loss and possibly other difficulties. Furthermore, there is an increase of electrostatic capacity, due to the presence of ground-wires in the neighborhood of the high-pressure conductors. These objections may be much less critical on low pressure, short-distance plants. In some such plants ground-wires may turn out to be the best ultimate protection.

Experience shows that direct strokes of lightning must be expected on transmission lines in most localities. Unless grounded guard-wires are used, these strokes must inevitably injure poles. Such injuries, however, often do not cause a shutdown of the plant. It is highly desirable for these severe discharges to get to earth as quickly as possible.

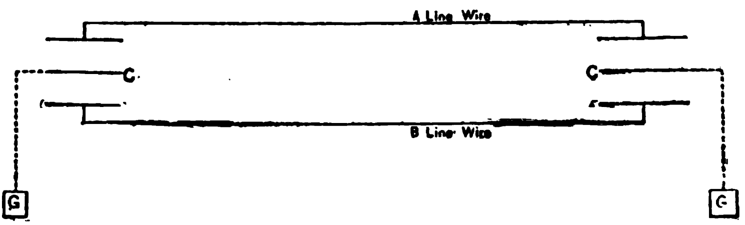
Arresters in the station constitute the most approved practice and will be relied upon in most cases. In very important high-pressure plants, however, it would seem that where regular attendance is feasible a set of arresters at a point from one-half a mile to two or three miles from the station would be a very desirable precaution. In such cases where constant attendance is not feasible, but where there is a suitable location for arresters, the use of fuses, possibly arranged so that when one blows another comes into service, would be satisfactory. In such cases, should trouble occur at the arresters, the line would clear itself immediately.

Reactive coils may serve two functions: the prevention of short-circuit strains between the turns of windings, for which purpose they are especially suited, and to assist the discharge of lightning-arresters to ground by delaying the rise of pressure of a transformer terminal at a time of static disturbance. In either case the protection derived from the reactive coil is a matter of degree, depending upon the relative electrical characteristics of the transmission line, the windings of apparatus, the arresters, and the pressure of line. A given coil may be very effective on one circuit at one pressure, and entirely inadequate for another circuit on another pressure. A freely-discharging arrester on a line of small electrical capacity, protecting apparatus itself having a large electrostatic capacity near its terminal, would require comparatively the smallest choke-coil for restraining the ultimate rise of potential above ground. An arrester with a ground-

connection on a line of large electrostatic capacity and high-pressure, where the apparatus to be protected has a comparatively small electrostatic capacity near the terminal, would require a coil very many times more powerful to obtain the same protection to ground than the coil of the first case.

For the protection against short circuits in windings, the choke-coil must be proportioned in its choking power to the number of turns, etc. and the winding itself, at least approximately; and to be effective without being unduly large can oftentimes be advantageously assisted by the use of a condenser connected between the terminal of transformer and ground. It would seem evident from the above that reactive coils should be of a power adapted to the circuits upon which they are to be used.

N. M. SNYDER (by letter): On the assumption that the line-wires of a transmission line have capacity, it might be said that when we use an overhead ground-wire as suggested, the nature of the protection afforded seems to be due to the static charges surging from the line-wires to the ground-wire, as evidenced by the jumping of the arc across the transformer leads above the oil. This shows capacity in the circuit. The writer concurs with Mr. Wirt in saying that we should be able to protect stations and apparatus without resorting to the use of the ground-wire. If we make the same conditions at the station as existed when the grounded line was used, it should be of material benefit. If we connect a plate or series of plates,



equal in capacity to the wire to be protected, at the power-house and sub-station and do this with all wires, arranging them symmetrically and equidistant from a central or ground-plate of equal area, should we not have an ideal static arrester? As long as the wire or wires are balanced and current is flowing equally in all, no interference should be experienced in retardation by the ground-plates, nor any serious faults from resonance. A static disturbance occurs; it surges from wire to wire as through a condenser; the ground-plate is neutral to the plates of the wires; so any charge of static on either wire will promptly be communicated to the ground-plate and relieve the strain. Of course in adjusting the plates care should be taken to have them sufficiently separated to exceed 25 per cent. higher pressure than that of the generator. This

will prevent the breaking down of the air-gap, the principle being to make a static line balance normally; and when any excess of static occurs it is quietly induced to earth in an efficient manner by making use of the condenser principle.

JOHN PEARSON (by letter): There is one point in regard to the grounded wire with which the writer thoroughly agrees. The writer considers that the grounded wire cannot well be used: first, on account of cost; secondly, because with this wire a short circuit may easily be established; thirdly, because it does not afford complete protection to apparatus at generating or distributing stations. For more than three years the writer has been with a company operating a 4000-h.p. power-plant (not using the grounded wire) located near Somerset, Wis. This plant transmits current to St. Paul, 28 miles distant, at 25 000 volts pressure. During this time only three poles were split so that they had to be removed, but not so badly as to interfere with the operation of the plant. Another plant, only four miles distant, with a pole-line running through a hilly country, and not using the grounded wire, has not suffered at all from poles being shattered by lightning; but it has suffered a great deal from lightning, due to inefficient lightning-arresters.

From this and other data, it seems that lightning- and static-arresters can be arranged so as to be of more protection than the grounded wire. Experience proves it necessary to provide: first, an easy path from line to ground, through which the line wires may be relieved of high pressure in respect to the ground; secondly, to provide choke-coils between arresters and apparatus to be protected, so as to give the arresters more time to discharge; thirdly, to provide the multiplex connection which Mr. Wirt suggests on the arrester side of choke-coils so as to provide an easy path from line to line; fourthly, to provide the high-pressure winding of transformers (or generators) with a static by-pass between sections of such windings. This is done by bringing out a number of leads, at equidistant points, from the high-pressure winding of a transformer or generator to be protected, to provide metal knobs and series resistance between these leads, so that normally this combination is a non-conductor, but at say 50% increase in pressure across a section this combination becomes a conductor, and relieves the particular section which it is designed to protect.

The writer knows that when the lightning-arresters which are connected to the *line side* of choke-coils discharge, great differences of pressure are set up between wires on transformer or generator side of choke-coils. This difference of pressure frequently causes a flash from lead to lead in transformer top, and sometimes will break down the insulation between layers in transformer coils, especially the layers next to line wires. An efficient remedy for this is to provide an easy path for the discharge outside of the transformer top,

by bringing out leads and joining as suggested above. One feature about connecting a static by-pass over successive sections of the winding is that it will take no more pressure to break down all the air-gaps across the whole transformer winding than it will take to break down the air-gap across a single section, owing to the fact that all the gaps are not broken down at the same instant. This idea in transformer protection has been used for over two years at St. Croix Power Co.'s

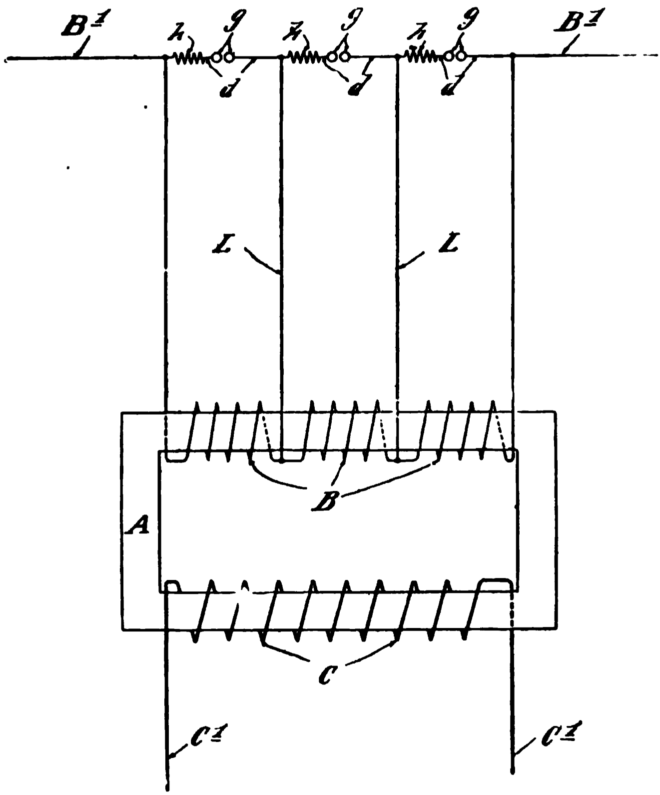


FIG. 1.

plant, Somerset, Wis., and has also been installed at a new plant in New York State.

Prior to using this form of protection for transformers, the St. Croix Power Co. lost four transformers in one season, caused by static jumping from lead to lead in transformer top; since then there has been no loss from similar causes. In Fig. 1, *A* represents the core of a high-pressure transformer; *C* the low-pressure winding; *C′—C′* terminals of this winding. *B* represents the high-pressure winding; *B′—B′* represent the terminals of this winding. Leads *L-L* are brought out between

terminals of this winding, dividing it into three sections in regard to static-arrester, and between these leads are provided non-inductive resistance, *h*, metal knobs, *g*, with their air-gap, also wire (or conductor) *d*.

Fig. 2 shows this scheme connected to a high pressure generator with revolving field. The connection is the same as in

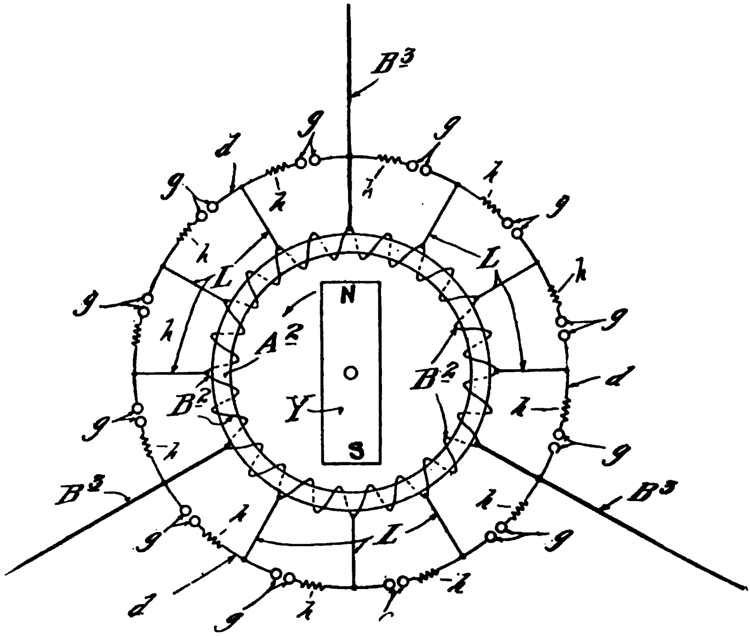


FIG. 2.

Fig. 1. Referring to Fig. 1, it can easily be seen that there exists great strains between *B′-B′*, due to lightning arresters discharging or other causes (this charge being of an oscillatory nature); each one of the air-gaps is broken down successively, one after the other, and it will take no more strain to break down all the air-gaps than it will take to break down a single gap.

ANSWERS TO QUESTIONS RELATIVE TO HIGH-TENSION TRANSMISSION.

The answers to questions printed in this report have been gathered from authoritative sources. These answers indicate present electrical engineering practice; but it should be understood that the Institute merely transmits the information contained in the answers, and that neither the Institute nor the Committee on High-Tension Transmission assumes any responsibility as to its correctness or its reliability as a guide to best engineering practice.

At a meeting of the Board of Directors of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, held September 26, 1902, it was

"RESOLVED, That a Committee on High-Tension Transmission, consisting of five members, may be appointed for the purpose of collecting data respecting present practice in electric transmission at high voltage and of presenting a report which will indicate the successful methods which are now in operation in such form as to be of immediate value to electrical engineers. It is within the scope of the Committee to secure data upon line construction, insulators, pins and the like, and the conditions of operation at different voltages and under different climatic conditions; to investigate methods of testing insulators and to indicate the method or methods which in its judgment are superior. Also to ascertain the methods employed for voltage regulation, the conditions attendant upon the switching of high-tension circuits and to collect data respecting lightning and static disturbances and the use of grounded protective wires."

In accordance with this resolution the Transmission Committee prepared a list of questions, copies of which were sent to those connected with and operating transmission plants, with the request that the answers to the questions be filled in and the lists returned. Although the number of replies received fell far below the number hoped for, a considerable amount of information was obtained. The following matter presents in condensed form the answers received. For convenience in presentation, the plants have been classified with respect to the voltage of transmission.

Total number of plants that have filled out lists to date, 47. These plants are classified as follows:

Class A. Plants transmitting under 12 500 volts.
B. Plants transmitting from 12 500 to 19 000 volts.
C. Plants transmitting from 20 000 to 24 000 volts.
D. Plants transmitting from 25 000 to 29 000 volts.
E. Plants transmitting from 30 000 to 39 000 volts.
F. Plants transmitting from 40 000 to 60 000 volts

I. LINE IN GENERAL.

3. *What is the distance of transmission?*
4. *What is the transmission voltage at the generating end and at the receiving points?*
5. *Is the transmission single-phase, quarter-phase (two-phase), or three-phase?*
6. *What is the frequency?*
7. *How much power is transmitted?*
8. *What is the average power-factor at the generating station and at the sub-stations?*
14. *What is the distance between conductors?*

(For answers to these questions see Table A.)

TABLE A.

Class.	Number of plants.	Transmission voltage.			Total mileage of transmission lines.	Total power transmitted in kilowatts.	Length of Lines in miles.			Phase			Frequency, cycles per second.						Range of power-factor	Distance between conductors in inches		
		Maximum.	Minimum.	Average.			Maximum.	Minimum.	Average.	Single	Two	Three	25	30	33	50	60	66		Maximum.	Minimum.	Average.
A	19	12 000	4 600	8 000	217	31 135	25	3	9.5	1	4	14	2	1	2	—	14	2	80 to 100	36	14	19
B	7	16 000	14 500	15 000	297	65 425	31	7	23	—	—	7	2	1	—	1	3	—	80 to 97	40	18	27
C	9	24 000	20 000	22 600	394	64 999	60	107	32	—	—	9	2	1	—	—	5	1	80 to 90	48	26	33
D	4	27 000	25 000	25 500	127.50	23 400	46	16.6	32	—	—	4	—	—	—	—	3	1	80 to 90	50	18	39.5
E	4	34 000	30 000	31 300	276.30	18 825	83	29	62	—	—	4	1	—	—	1	2	—	90 to 95	40	24	31
F	4	60 000	40 000	51 600	328.25	14 875	101	60	75	—	—	4	—	1	—	—	3	—	65 to 100	108	42	76

12. *How many complete circuits are there on each pole line?*
13. *What is the standard distance of the lowest conductors above the ground?*
15. *What length of span is standard?*
16. *What is the longest span used with standard construction or modification of it?*
24. *What is the greatest deflection of line ordinarily allowed on a single angle-pole?*
25. *Do angle-poles have double fixtures?*
26. *Are angle-poles braced or guyed? If guyed, at what point relative to the power wires are the guys attached? (A sketch is desirable.)*
27. *What is the normal length of span between angle-poles?*
28. *If guys are used, do you use strain insulators in the guys?*
32. *Are the power wires transposed? If so, how many times and at what intervals of distance?*

(For answers to these questions see Table B.)

TABLE B.

Class.	Max. no. of complete circuits on one pole line.	Height lowest conductor is above the ground in feet.	Standard length of span in feet.	Longest span with standard const. feet.	Max. deflection allowed on ordinary single pole (horizontal.)	No. of plants using double fixture on angle-poles.	No. plants that guy or brace angle-pole.	Length of span between angle-poles.	No. of plants using strain insulators in guys.	No. of plants that transpose lines.
A	9	18 to 40	80 to 125	100 to 240	10° to 90°	17	15G. 2G&B	50 to 130	11	8
B	3	15 to 32	80 to 125	100 to 175	10° to 60°	6	7G	20 to 100	6	5
C	2	15 to 27	90 to 140	100 to 300	12° to 30°	9	3G 2B 4G&B	12 to 100	4	8
D	2	25 to 35	90 to 130	125 to 200	15° to 45°	4	1G 2B 1G&B	50 to 90	2	3
E	2	19 to 27½	100 to 130	360 to 400	45°	3	3G 1B	80 to 120	1	4
F	1	19½ to 30	100 to 180	200 to 320	10°	1	1G 1G&B	110	0	4

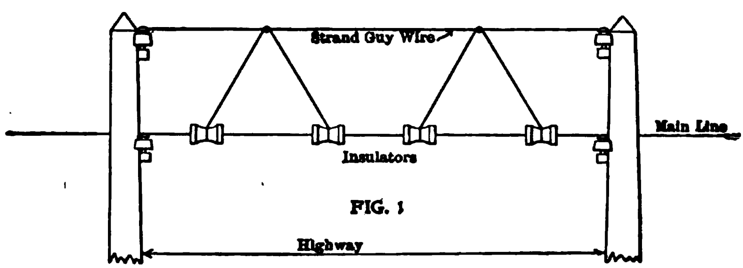


FIG. 1

18. *What heavier construction, if any, is used on such spans?*
19. *What is the longest span of any kind?*
20. *What is the distance between wires on this span?*

General Description of Construction Used in Extra-Long Spans.

Spans to 300 feet: the poles are usually double cross-armed and guyed; in some cases double poles are also used.

Span 626 feet: double poles, double cross-arms guyed two ways, and wires were spaced eight feet apart.

Span 800 feet: double poles and 6 by 6 in. cross-arms, poles guyed with steel cable two ways.

Span 586 feet: six poles, two poles for each wire, a cross-arm bolted on top of each pair of poles with four insulators in it; the six poles are framed together and braced in all directions.

Span 1750 feet: two poles set 10 feet apart, 66 feet high, 10-in. tops, $\frac{3}{8}$-in. steel cable was used on this span, it being constructed to take the place of a pole line across a dry river bed in case of washout. Factor of safety is only 1.6 on this span and has withstood winds of 90 miles per hour. It is supported by compression strains on insulators whose pins stand radially around the beam; six feet between wires.

Span 400 feet: four poles set same as a tower and held together, also guyed; double cross-arms, wires spaced four feet apart.

34. *Do you consider transposition necessary so far as the power line itself is concerned? If so, why?*
35. *Do you consider the transposition of the power lines necessary for the protection of adjacent telephone and telegraph wires?*

Reasons for Transposing Power Line.

One company thinks transposing of power lines is not necessary for lines up to 30 miles and voltages under 20 000, but for distances and voltages in excess of these, thinks it better as power wires are more symmetrically located as regards the earth.

One company does not think transposing is necessary when synchronous converters are used at intervals along the line.

One company thinks it is decidedly necessary to transpose power lines, their principal reasons are; the lack of interference with telephone and telegraph wires running parallel, and the more spiralling, the less apparent impedance.

Another company does not think it necessary to transpose power lines when there is only a single line on poles; they think it is advisable if not absolutely necessary to transpose power lines as a protection to adjacent telephone and telegraph lines.

Out of 23 companies that express opinions on the necessity of transposing or not transposing the power lines so far as the power line itself is concerned, 15 think it is not necessary, and nine of the 20 think it is not necessary to transpose power lines as a protection to adjacent telephone and telegraph lines.

29. *Are braces used on the cross-arms? If so, of what material and how constructed? (A sketch is desirable.)*
30. *How are the cross-arms attached to the poles, and how deep are poles gained?*

Methods of Bracing and Fastening Cross-Arms to Poles.

Class A.

Majority of cases, strap-iron braces 1¼ by ¼ in. are used.
In one case angle-iron braces are used.
In three cases strap-iron galvanized braces are used.
In one case no bracing is done.
In eleven cases through bolts are used to fasten cross-arm to pole.
In six cases lag-screws are used to fasten cross-arm to pole.
Through bolts average from ⅝ to ¾ in. in diameter.
Poles are gained from ½ in. to 3 in. deep.

Class B.

Strap-iron braces are used in all cases.
In one case the strap-iron braces were galvanized.
In four cases through bolts were used to fasten cross-arm to pole.
In three cases lag-screws were used to fasten cross-arm to pole.
Gains ½ in. to 2 in. deep.

Class C.

In two cases wooden braces are used.
In three cases strap-iron braces are used.
In one case strap-iron braces were galvanized.
In two cases 1¾ by 1¾ angle-iron braces were used
In two cases no braces were used.
In seven cases bolts were used to fasten cross-arms to poles.
In one case bolts were galvanized.
In two cases lags were used, average ⅜ in. to ⅝ in. diameter.
Gains ⅝ in. to 1½ in. deep.

Class D.

In two cases strap-iron braces were used.
In one case no braces were used.
In two cases through bolts were used to fasten cross-arms to poles.
In one case ½ in. lag screws were used to fasten cross-arms to poles
Gains ¾ in. to 1 in. deep.

Class E.

In three cases strap-iron braces were used.
In one case only one brace used on each cross-arm.
In one case strap braces were galvanized.
In one case angle-iron brace on one side of cross-arm.
In three cases ¾ in. through bolts were used.
In one case lags screws were used.
Gains ½ in. to 2 in. deep.

Class F.

In three cases no bracing done.
In one case white oak ¾ in. by 3 in. was used.
In one case cross-arms were mortised through pole.
In one case two ⅝ in. bolts were used.
In one case two ⅝ in. lags screws were used.
Gains 1¼ in. deep.

(See sketches showing various arrangements of conductors on cross-arms, p. 396-399

37. *In crossing other power lines, telegraph or telephone lines, railroads or highways, are there any special precautions taken against the danger of the power lines breaking and falling? If so, what?*

VARIOUS METHODS OF CROSSING OTHER POWER LINES, TELEPHONE OR TELEGRAPH LINES, AND RAILROADS AND HIGHWAYS.

Class A.

1. Extra cross-arms and idle wires.
2. Double pole fixtures and short spans.
3. Guard wires underneath power wires.
4. Extra-high poles.
5. A ground net of $\frac{1}{4}$ in. steel cable suspended across railway right of way under power wires and six feet below them.

Class B.

1. A grounded network of iron wire under power line.
2. Extra-high poles.
3. Telegraph lines put under ground.

Class C.

1. Guard net under power wires.
2. Truss bridges built across railway track upon which power wires are supported.
3. Guard wires placed over telegraph wires.
4. High poles.

Class D.

1. Short spans and double fixtures.
2. High poles placed eight feet apart, telephone line passes between.
3. Bronze cables used over railway crossing.
4. Telegraph wires put in cable underneath.

Class E.

Guard wires.

Class F.

1. Twelve foot span and high poles.
2. Guard wires.
3. A grounded net made of $\frac{3}{8}$ in. steel cable suspended between poles over railway right-of-way about six feet under power wires.

40. *Are there automatic overload devices arranged for cutting off the individual sub-stations from the power line?*

The following automatic overload devices are used for cutting off the individual sub-stations from the power line:

Class A.

Four plants use high-tension fuses.
One plant uses high-tension fuse-switch operated by hand.
Two plants use automatic oil-switch.

Class B.

One plant uses high-tension fused cut-outs.
One plant uses fuse-switch.
One plant uses air-brake circuit-breakers.

Class C.

One plant uses fuse circuit-breaker.
One plant uses oil-switch.
One plant uses oil circuit-breaker.
One plant uses automatic circuit-breaker.

Class D.

None.

Class E.

One plant uses fuses.
Two plants use fuse-switch.

Class F.

Two plants use oil-switch.
Two plants use fuse.

41. *Are the intermediate sub-stations sources of much trouble? If so, what?*

VARIOUS SOURCES OF TROUBLE AT INTERMEDIATE SUB-STATIONS.

Class B.—One company had trouble with their rotaries but had cross-circuiting rings put between each armature section. O.K. now.

Class C.—One company had endless trouble with double-current generators; armatures burning out. One company has had trouble due to defective switching apparatus.

43. *How are the wires carried into the power house and into the sub-stations? (A sketch is desirable.)*
44. *How is the support arranged just outside of the building, and just inside of the building? (Sketch.)*

(See sketches showing various methods of bringing lines into power houses and sub-stations Figs. 2–15.)

45. *Do you have switches located outside to cut the wires entirely clear of the sub-stations?*

No. of plants that have switches located outside to cut the wires entirely clear of sub-stations.

Class	A	B	C	D	E	F
	8	0	3	0	1	1

II. CONDUCTORS.

47. *Of what material are they made?*
48. *Are they solid or stranded? If latter, how many strands or separate wires?*
49. *If of copper, are they hard drawn, medium drawn, or soft drawn?*
50. *Are they bare or insulated?*

KIND OF CONDUCTORS.

Class A.

Six plants use solid copper hard drawn.
Seven plants use solid copper medium drawn.
Four plants use solid copper soft drawn.
One plant uses 19-strand aluminum.
One plant uses 7-strand aluminum.
Twelve plants use bare conductors.
Seven plants use waterproof insulated conductors.

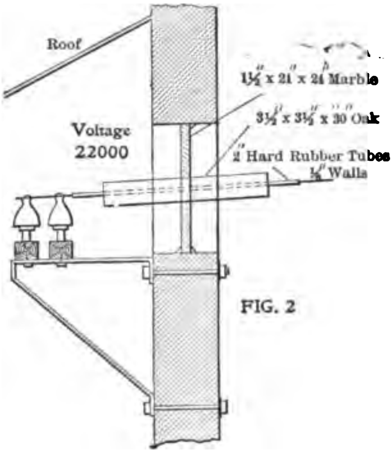


FIG. 2

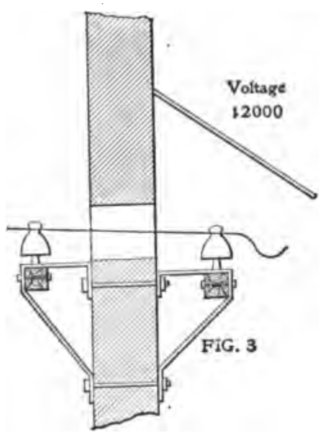


FIG. 3

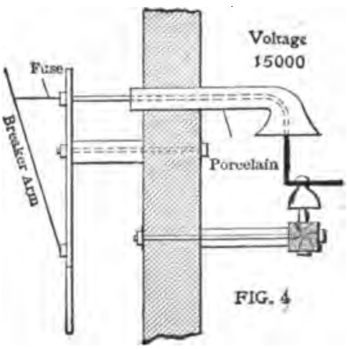


FIG. 4

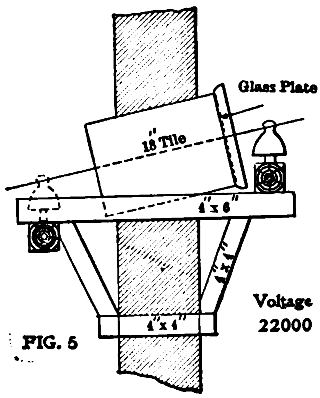


FIG. 5

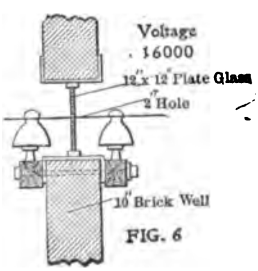


FIG. 6

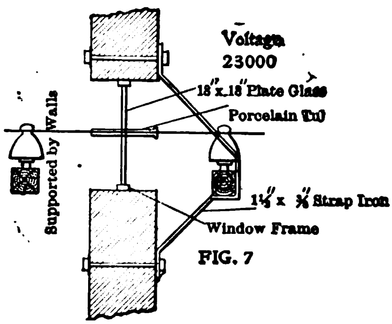


FIG. 7

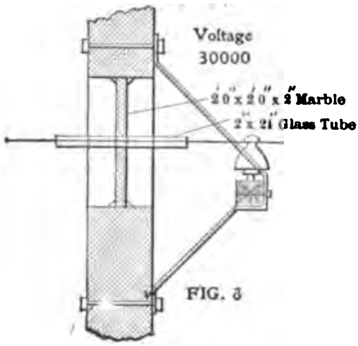


FIG. 8

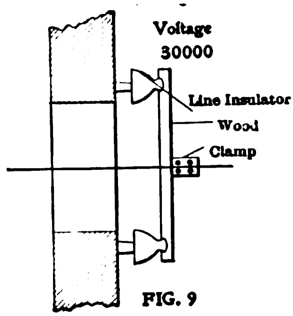


FIG. 9

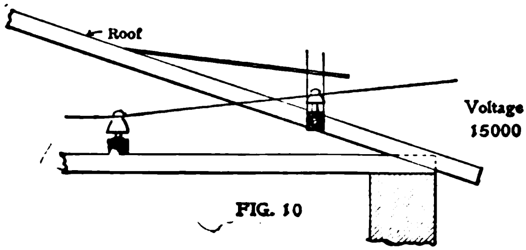


FIG. 10

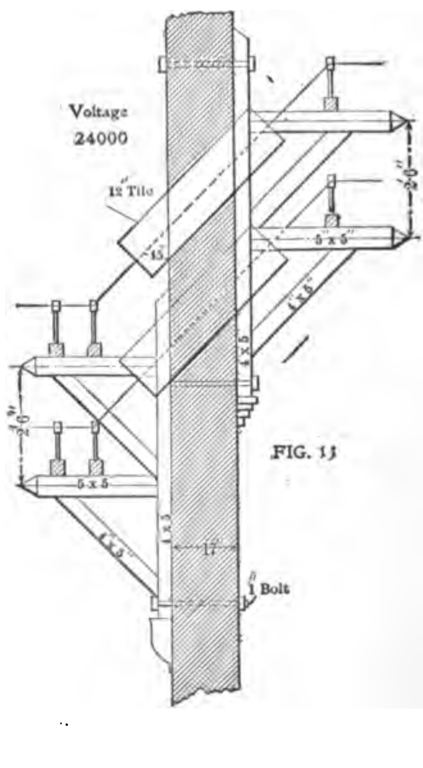


FIG. 11

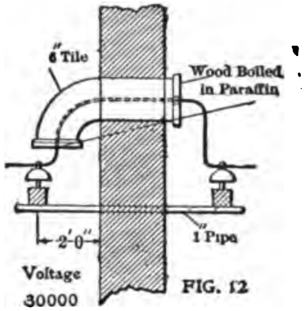


FIG. 12

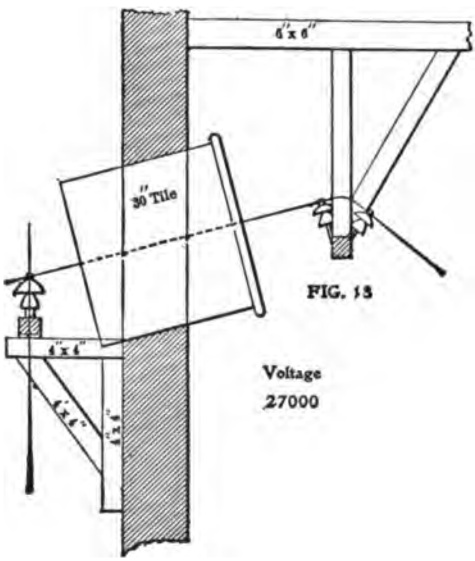


FIG. 13

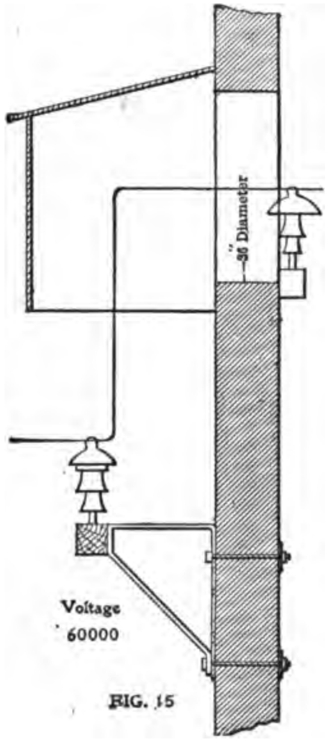


FIG. 15

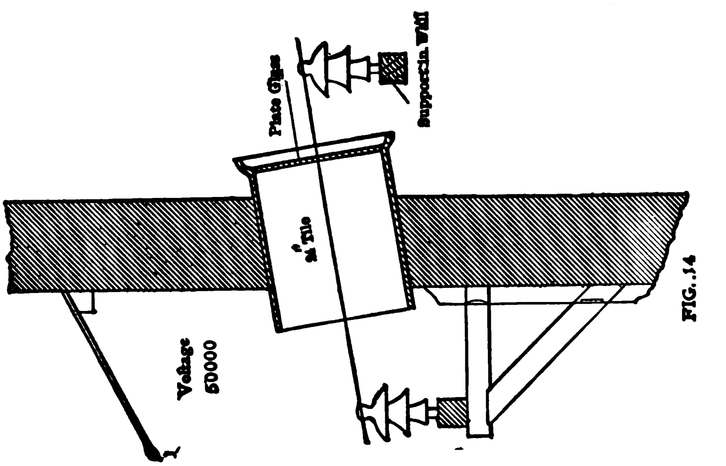


FIG. 14

Class B.

Two plants use solid copper hard drawn.
Two plants use solid copper medium drawn.
Two plants use solid copper soft drawn.
One plant uses stranded aluminum.
Five plants use bare conductors.
Two plants use waterproof insulated conductors.

Class C.

Three plants use solid copper hard drawn.
Three plants use solid copper medium drawn.
Three plants use stranded aluminum.
All plants use bare conductors.

Class D.

One plant uses solid copper hard drawn.
One plant uses solid copper medium drawn.
One plant uses solid copper soft drawn.
One plant uses 7-strand aluminum.
All plants use bare conductors.

Class E.

One plant uses 7-strand copper soft drawn.
One plant uses solid copper medium drawn.
Two plants use 7-strand aluminum.
All plants use bare conductors.

Class F

Two plants use solid copper medium drawn.
One plant uses solid copper hard drawn.
One plant uses solid aluminum.

51. *Have you had any serious amount of corrosion of conductors due to any causes? If so, what are the causes?*

Only two plants have experienced trouble with conductors corroding; viz., one company has one sub-station at a chloridizing quartz mill; the gases corrode the copper and cover the glass line-insulators with a film. The other company has its copper lines corroded by chemical fumes.

52. *If the conductors are aluminum, have you found them satisfactory? If not, why?*

One company experienced a great deal of trouble with their solid aluminum line; cause being that the aluminum crystalized due to the continuous vibration, and used to break frequently.

53. *Is high-tension wiring inside of buildings done with bare or insulated wire, and if the latter, what kind and thickness of insulation?*

54. *What kind of insulators are used for this interior wiring?*

The majority of plants use rubber-insulated wire for their interior wire (high tension) the thickness of rubber varying from $\frac{3}{32}$ in. to $\frac{1}{2}$ in. The balance use bare wire, with the exception of four or five plants which use paper or rubber lead-covered cable laid in ducts. The interior wiring in classes A and B is held on porcelain cleats and knobs in the majority of installations. In classes C, D, E, and F the ordinary line insulator is generally used to support the interior high-tension conductors.

III. LINE INSULATORS.

55. *Are the insulators glass or porcelain?*
56. *What is name of maker and what is the trade name or designaiion for them?*
57. *Have you any preference as to material and if so, why?*
58. *If porcelain, are they tinted, and what color?*
60. *Are the wires carried upon the top or the side of the insulators?*
61. *What tests were given the insulators before installing?*
62. *At what voltage will a flash occur between wire and pin when being sprayed with water?*
63. *At what voltage will they puncture?*
64. *Have you found your insulators satisfactory, if not what has been the trouble and to what has it been due?*

TABLE C.

Class.	Material.			Color.		Method of Tying.		Tests.		Makers.
	Porcelain.	Glass.	Porcelain and Glass.	White.	Brown.	Side of Insulator.	Top of Insulator.	Puncture Volts.	Spray Volts.	
A	6	9	3	7	2	6	11	20 000 to 50 000	—	R. Thomas & Son Co. Hemingway Glass Co. Imperial Porcelain Works. C. S. Knowles. F. Locke & Co. General Electric Co. Redlands Co. Guion, Italy.
B	2	4	1	3	1	4	2	40 000 to 50 000	25 000	
C	4	4	1	3	3	4	3	50 000 to 75 000	—	
D	2	2	—	1	1	2	1	80 000 to 120 000	—	
E	4	0	0	4	0	4	0	60 000 to 90 000	35 000 to 55 000	
F	2	1	1	1	1	1	1	120 000 saltwater	70 000	

Notes.—Prefer porcelain to glass on account of greater mechanical strength; greater dielectric strength; less liability to creeping of static over surface.

Prefer glass to porcelain on account of defects being easier detected by inspection; less tendency for dirt to hold on.

Four companies had trouble with tops breaking off glass insulators at grooves, due to changes in weather, etc. Two companies had trouble with glazed filled insulators, the insulator cracking at the joints.

One company had trouble with film forming on glass insulator from quartz mill.

IV. CROSS-ARMS.

65. *What are the dimensions of the cross-arms?*
66. *Of what material are they made?*

Sizes vary from $2\frac{1}{8}$ in. by $4\frac{3}{4}$ in. to $4\frac{1}{2}$ in. by 9 in., the average section being $3\frac{1}{4}$ in. by $4\frac{1}{4}$ in.

The majority of plants use yellow pine, other woods used are: white pine, yellow fir, Oregon pine, spruce, Oregon fir, peroba, and cabreura, the last two being Brazilian woods.

67. *If of wood, have they been treated in any way? If so, in what way?*

The following are different methods of treating cross-arms:

(1) Painted with white lead.
(2) Painted with mineral red in oil.
(3) Painted two coats.
(4) Painted coal tar.
(5) Painted two coats metallic paint.
(6) Treated with carbolinium.
(7) Boiled in linseed oil two or three hours.
(8) Dipped in bitumen paint.
(9) Dipped in creosote.

V. POLES.

68. *What kind of poles? Steel or wood? If wood, what kind?*

Majority of plants use cedar poles. Other woods used are: chestnut, juniper, cypress, red cedar, tamarack, Idaho cedar, spruce, and white cedar.

71. *What are the dimensions of the tops of the different lengths of poles, also the minimum diameter of the butts?*

$$\left.\begin{array}{l}\text{Tops vary from 5 in. to 8 in. in diameter.}\\ \text{Butts vary from 9 in. to 24 in. in diameter.}\\ \text{Average top is 7 in.; average butt is 12 in.}\end{array}\right\}\begin{array}{c}\text{Poles vary from}\\ \text{25 ft. to 45 ft. long.}\end{array}$$

72. *How deep are the different lengths of poles set into the ground?*

Poles are placed in ground from 4 ft. to 8 ft. according to their length and condition of soil.

Poles were treated in the following ways:

74. *Are the poles treated in any way? If so, how? Are they painted?*

(1) Gains painted with metallic paint.
(2) Butts tarred.
(3) Poles painted.
(4) Butts painted.
(5) Tops painted.
(6) Butts treated with carbolinium.
(7) Tops painted with linseed oil.
(8) Butts burned and tarred.
(9) Butts painted with asphaltum.

75. *How are the tops finished?*

Majority of plants roof the tops of the poles.

A large percentage paint tops of the poles.

One plant puts cast-iron caps on poles.

One plant champfers the pole tops to pin that is in end of pole, and binds No. 6 galvanized-iron wire around end, and paints top with P. & B. paint.

76. *Is there a pin in the top of the pole, and if so, is there a metal band around the top?*

Four companies that have pin in top of the pole have an iron ring around pole.

One company uses a composite pole made with a 7-in. iron pipe, socket 13 ft. long, Australian jarra wood top 7 by 7 in., 17 ft. long, pressed into the socket; this pole is placed 6 ft. in the ground. Poles are tarred, and a galvanized-iron cap is put on top of pole. A few companies use octagonal and square poles.

Kind of Wood.	Location.	Life of pole in years.
Red Cedar	Ohio	20
Cedar	Oregon	10–15
"	California	10–15
"	Idaho	15
"	Montana	6–7
"	Washington	10–15
"	Minnesota	14–16
"	Pennsylvania	9
"	Canada	15
Chestnut	New York	8–14
"	Pennsylvania	8
"	Massachusetts	8–12
" (2d growth)	Pennsylvania	12–16
Juniper	Georgia	15
Cypress	Carolina	8
Tamarack	California	5
Pine	Pennsylvania	8

69. *What is the length of their life and on what peculiar conditions, if any, does this depend?*

78. *Give dimension sketches of pole-head, showing cross-arms, pins, and insulators.*

See dimension sketches on pages 396-399

73. *Are any of the poles set in concrete or otherwise, giving additional solidity in the earth?*

The following methods are used for poles in boggy or swamp land:

1. Set in concrete.
2. Tamped with broken stone.
3. Protected by rock cribs.

VI. PINS.

79. *Of what material are the pins made?*
80. *If of wood, what kind of wood?*

Classes A, B, C, and D.

In these classes the standard 1½ in. locust pin is used in most cases; other kinds of pins used are: black locust, oak, eucalyptus, hickory, iron with wooden thimbles, porcelain, and iron ⅝ in. fastened into insulators with cement.

Classes E and F.

Following kinds of pins are used:

1. Iron pins held into insulator with Portland cement.
2. Iron pins, wooden thimble, porcelain base.
3. Locust and eucalyptus.
4. Steel pin and cast-iron bushing in cross-arm (see sketch).

81. *Are they treated, and if so, how?*

Pins are treated in the following ways:

1. Boiled in paraffin about 24 hours.
2. Boiled in linseed oil about two hours.
3. Painted.
4. Dipped in elastic bitumen.

In a great many cases pins were not treated in any way.

In all cases where wood pins were used they were boiled in paraffin for 24 hours.

83. *Are the pins fastened in the cross-arm and pole, and if so, how?*

Pins are fastened to cross-arms in the following ways:

1. Nailed (in most cases).
2. Nut and washer (when iron pins are used).
3. Wooden dowel (in one case).
4. Iron spring (in one case).
5. Driven into cross-arm tightly.

The following methods are used to hold pins in cross-arms and poles:

1. Pins screwed into top of pole.
2. Nut and washer (iron pins).
3. Nailed through cross-arm.
4. ½ in. and ¾ in. oak dowel.

82. *What are the dimensions of the pin? (A sketch is desirable.)*

See sketches showing various size pins, Figs. 16-21

VII. TELEPHONE LINE.

85. *Have you telephone lines upon your transmission poles?*

All plants with the exception of four have telephone lines on same poles as the power lines. One plant in Class F has its telephone line on separate poles 200 feet from the power line.

87. *What kind of pins, insulators, and cross-arms or brackets are used?*

Majority of plants use standard side brackets, cross-arms, pins, and glass telephone insulators.

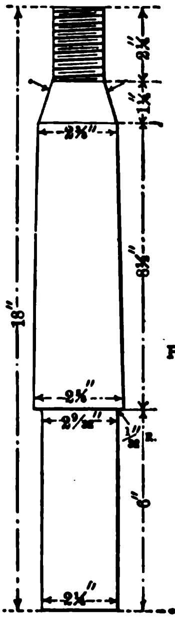


Fig. 16

27000 Volt Pin

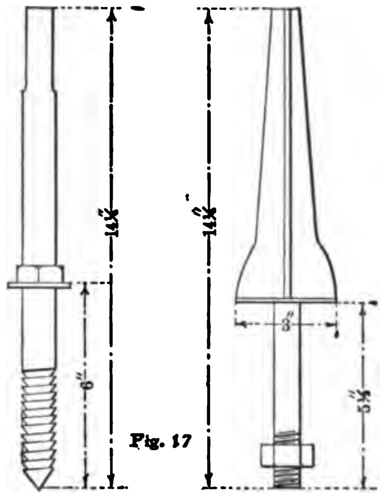
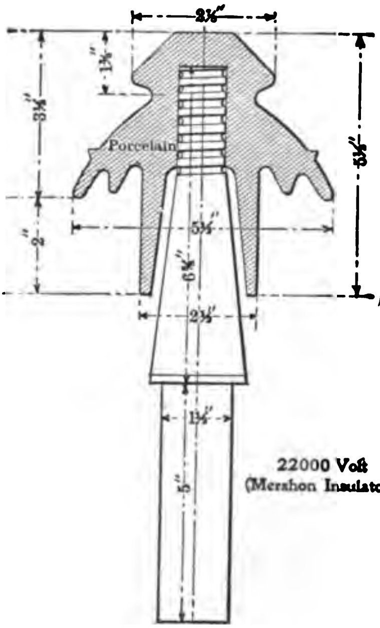


Fig. 17

Top Pin

Cross Arm Pin

30000 Volt Iron Pin



22000 Volt
(Mershon Insulator)

FIG. 19

30000 Volt
Insulator and Pin

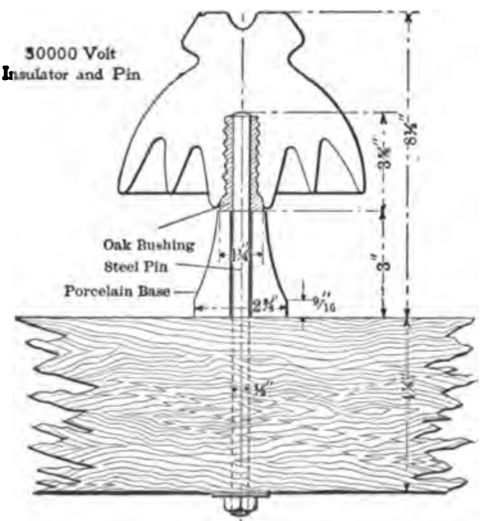
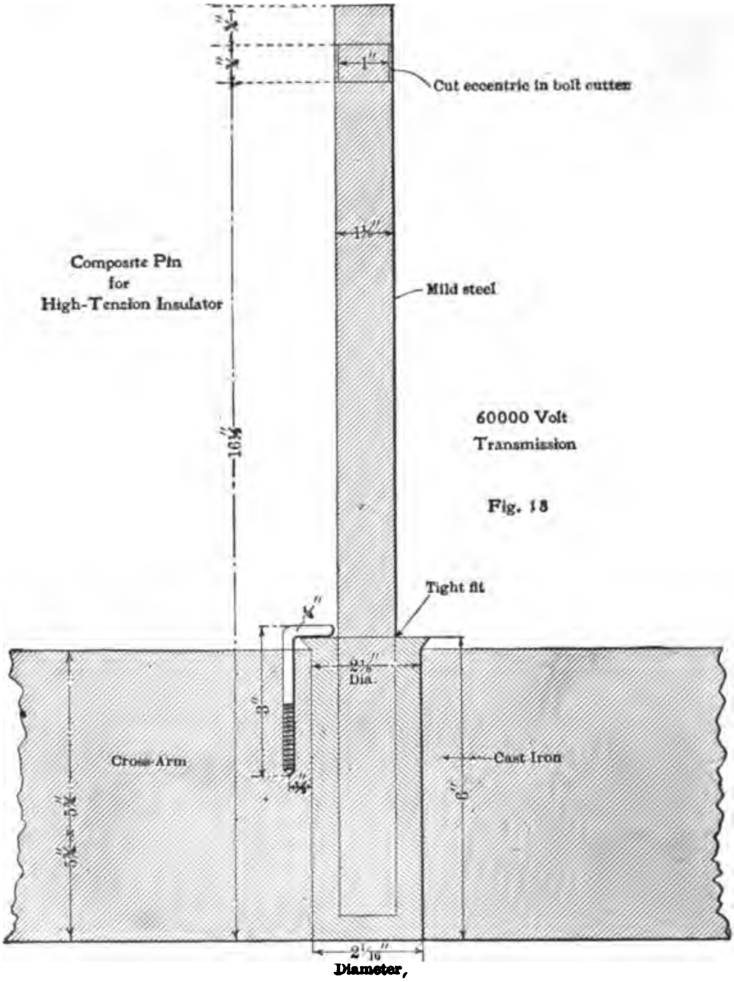


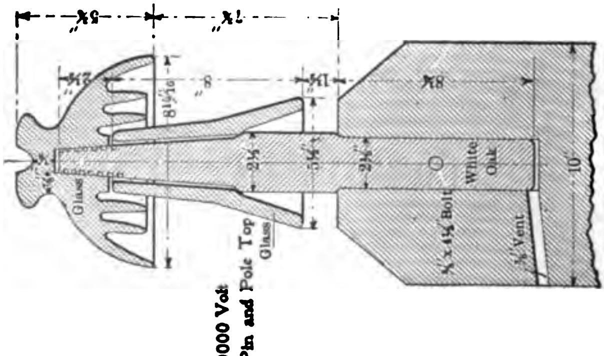
FIG. 20



Composite Pin
for
High-Tension Insulator

60000 Volt
Transmission

Fig. 18



60000 Volt
Insulator, Pin and Pole Top

FIG. 21

86. *How often are they transposed, and at what intervals of distance?*

The following are methods of transposing telephone lines:

Classes A, B, C, D.

Every 5 poles (approximately 500 feet).
Every 10 poles (approximately 1000 feet).
Every 4 poles.
Between every pole.

Classes E, F.

Every 2 poles.
Every 3 poles.
Every 1600 feet.

88. *Are the pins, cross-arms, or brackets treated? If so, how?*

Pins, brackets, and cross-arms are treated in the following ways:

Painted.
Paraffined.
Creosoted.
Linseed oil.
About one-half the plants do not treat pins, brackets, etc.

89. *What kind of conductor is used, and what size?*

The following are the kinds and sizes of telephone conductors:

No. 10 B. & S. copper hard drawn.
No. 10 B. & S. copper medium drawn.
No. 12 B. & S. copper hard drawn.
No. 10 B. & S. copper waterproof.
No. 6 galvanized iron.
No. 8 galvanized iron.
No. 9 galvanized iron.
No. 10 galvanized iron.
No. 12 galvanized iron.
No. 12 galvanized steel.
No. 10 B. & S. aluminum.
The majority of plants use No. 10 galvanized-iron wire.

90. *Is the circuit an all metallic one?*

All telephone circuits are metallic.

91. *Do you have stations for tapping on to your telephone line or do your inspectors attach their portable telephone to the line wherever they may happen to be?*

In the majority of plants inspectors attach their portable telephones to the line wherever they may happen to be.

In one case stationary telephones are placed in booths every two miles.

In three cases stationary telephones are placed in boxes on the poles.

92. *If so, what precautions are taken for the safety of the users?*

The majority of plants have insulated platforms for users to stand on, these platforms standing on line insulators in most cases.

One plant makes its inspectors wear rubber gloves when using telephone.

93. *What is the normal distance between the nearest power wires and the telephone wires?*

The following are the maximum and minimum distances of telephone line from power lines:

Class A	B	C	D	E	F
2 ft. to 15 ft.	4 ft. to 10 ft.	4 ft. to 10 ft.	3 ft. to 6 ft.	4 ft. to 8 ft.	5 ft. to 8 ft.

96. *What means have you for the protection of the telephones, and those using them, from lightning and crosses with the power wires?*

The following means are used for protecting telephones and those using them from lightning and crosses with the power wires:

1. Lightning-arresters (in most cases).
2. Fuses to ground.
3. Film cut-outs.
4. Barbed wire.
5. Rubber hose on receiver cord.
6. Insulated stools or floors (in most cases).

97. *If you use telegraph instruments instead of telephone, state the reason why?*

One company (in Class F) uses a telegraph instrument for signaling. Two other plants use telegraph instruments, one of them only when telephone is not working.

98. *Show on sketch, position of telephone wires with reference to power wires, showing the normal distance apart of the telephone wires?*

See sketch showing position of telephone wires relative to power wires, pages 396-399

99. *What is the e.m.f., induced or other, between your telephone wires and the ground?*

Classes A, B, C, D.

Highest e.m.f. recorded between telephone wire and ground is from 20 to 130 volts.

Classes E, F.

In these classes highest e.m.f. was 3000 volts. A great many plants claim there is no e.m.f. between telephone wires and ground, due to: careful transposing; using good insulators and careful wiring; a reactive coil in line with middle point grounded.

VIII. TRANSFORMERS.

101. *What is the capacity of your transformer units in the power-house and sub-stations?*

Class A.

Transformer units at power-house range from 125 to 225 kw.; at sub-station from 7.5 to 375 kw.

Class B.

Transformer units at power-house range from 150 to 500 kw.; at sub-station from 75 to 300 kw.

Class C.

Transformer units at power-house range from 175 to 1400 kw.; at sub-station from 20 to 2250 kw.

Class D.

Transformer units at power-house range from 225 to 500 kw.; at sub-station from 125 to 350 kw.

Class E.

Transformer units at power-house range from 289 kw.; at sub-station from 150 to 500 kw.

Class F.

Transformer units at power-house range from 1000 kw.; at sub-station from 333 to 1000 kw.

102. *Are the transformers connected in $\triangle$ or Y?*

The following are the various methods of connecting transformers:

1. $\triangle$ (used in most cases).
2. Y.
3. $\triangle$ and Y.
4. Scott or T, two-phase to three-phase (used in a great many plants).
5. Single phase.

103. *Is the same connection used on both primary and secondary sides?*

In the majority of plants the same transformer connections are used on both primary and secondary sides.

104. *Is the neutral grounded upon either the high- or low-voltage side? If so, why? If not, why not?*

In the majority of plants the neutral is not grounded at all.

105. *Do you know any marked advantages or disadvantages in grounding the neutral? If so, state them.*

The advantages of grounding neutral are:

1. To prevent high-tension from doing damage to low-tension network, should insulation between primary and secondary break down.
2. Reduces strain on transformer and line under normal conditions.
3. Prevents accumulation.

In one plant neutral is grounded on high-tension side. The reasons for it: less expense in transformer construction; greater safety in insulation of windings; greater flexibility of general system in case of loss of transformers, or one wire of the circuit, or anything which cripples any one part of the three which go to make up the system, we can still operate on two until we can change to the other line and repair it, and have no interference with service. Greater simplicity in wiring of stations; less interference with telephone wires and outside circuits, and we believe, less opportunity for resonance and other serious line effects. At least, we have never had any of these effects.

Disadvantages are:

1. Increases danger of accident to apparatus.
2. Double-current generator is short circuited if neutral of secondary is grounded.
3. Liable to damage telephone system if power line should become grounded or open.
4. Increases liability to side flash from lightning

106. *Is there a spark-gap connection to earth from the centres of either the high- or the low-voltage coils?*

About two-thirds of the plants do not have spark-gap connections to earth from the centre of either the high- or the low-tension coils.

107. *Have the transformers ground-shields between the high- and low-tension windings?*

Only three plants have ground-shields between the high- and low-tension windings of their transformers, but majority of plants have their transformer cases grounded thoroughly.

108. *Are the transformers oil-insulated or dry?*
109. *Are they air-blast, water-cooled, or natural-cooled?*
110. *What is the voltage of the low-tension side?*

TABLE D.

Class	Oil-insulated natural-cooled	Oil-insulated water-cooled	Oil-insulated air-blast cooled	Dry air-blast cooled	Range of voltage on low-tension side.
A	11	3	1	5	360 to 2300
B	4	2	1	0	350 to 2400
C	6	2	1	1	390 to 2400
D	1	3	0	2	2200 to 2300
E	2	1	0	2	750 to 2400
F	1	4	0	0	1500 to 4000

111. *Is there transformation of phase as well as of voltage?*

Only about 6% of the plants transform the phase of the current.

112. *Have you had any trouble with your transformers? If so, what?*

The following troubles with transformers have been experienced:

1. Terminals improperly soldered.
2. Transformer burnt out; cause, not dried out enough before being put into service.
3. Breakdown between primary and secondary coils, bad insulation being the cause.
4. Breakdown from lack of proper circulating ducts between coils and from canvas hoods over ends of coils, making dead places for oil; oil would heat and burn.
5. Burnout from lightning discharges.
6. Burnout from overloading.
7. Burnout from defective leads.
8. In one plant six natural-cooled, oil-filled transformers furnished with the first contact were failures; had to be re-

designed; since, have been all right. Thirty air-blast transformers have never caused one dollar for repairs in five years—with one exception, which was due to an attendant not noticing that a terminal had become unsoldered where two banks were operating in parallel, and its mate burned out after carrying overload of 100% for at least 15 days.

IX. LIGHTNING PROTECTION.

113. *What devices are used to protect your power lines from lightning? Lightning-arresters, grounded wires, or both?*

With the exception of one plant which uses barbed wire, lightning-arresters are used; four plants use both lightning-arresters and ground-wire.

115. *Are the wires smooth or barbed and of what material?*
117. *How are they fastened to poles or cross-arms; on insulators? If on insulators, why?*

Barbed wire is generally used in preference to smooth wire. Some plants run taps to ground at every pole, some at only every four poles, and some at only every half mile. For mechanical reasons this ground-wire is generally run on insulators; but in some cases it is fastened to pole or cross-arms with staples.

118. *How is the ground made?*

The following are various methods of grounding this ground wire:

1. Twisting around butt of pole.
2. Gas-pipe driven into ground 6 ft. to 10 ft., the wire put into pipe and pipe filled with about 4 in. of lead.
3. Galvanized-iron plates placed in ground.

119. *Do you consider grounded wires as a valuable protection?*
120. *Do you consider them more or less desirable than any other means of lightning protection?*

Only nine companies consider grounded wires a valuable protection; as a rule they are thought less desirable than other lightning protection.

121. *If lightning-arresters are used, do you consider that they furnish any protection against rise of voltage, due to any disturbance upon the system, such as the throwing on or off of all or part of the load, etc.*

The majority of plants consider lightning-arresters furnish protection against rise of voltage due to any disturbance upon the system such as the throwing on or off of all or part of the load, but a number of plants think that for a moderate rise of voltage they furnish no protection.

122. *Do you consider them a complete protection against such rise?*

The majority of plants do not think lightning-arresters are a complete protection against such rises.

123. *What kind of lightning-arresters are used?*

The following makes of lightning-arresters are used (in order of the quantity):

General Elec. Co. (Wirts).
Westinghouse Elec. Mfg. Co. (low equivalent).
Stanley Mfg. Co.

124. *Do you have banks of lightning-arresters along your line? If so, at what intervals?*

Lightning-arresters are placed in the following ways along the line:

1. At power-house and sub-stations only.
2. At each end and middle point of line.
3. At points dividing line into four equal parts.
4. At irregular intervals (at cable terminals, etc.).

125. *Are they necessarily at sub-stations?*

The greater number of plants consider it necessary to have lightning-arresters at sub-stations.

127. *Is there resistance in series or in parallel with the arresters? If so, what kind of resistance (such as carbon, metal, water, etc.)?*

Lightning-arresters have the following kind of resistances in series or parallel, or both:

Carbon resistance in series.
Graphite rods in series.
German silver in series.
German silver in series and parallel.

128. *Is there capacity or inductance in series or in parallel, with the arresters or line?*

Majority of plants have choke-coils in series with line.

129. *Do you find that the lightning-arresters do their work satisfactorily? If not, wherein do they fail?*

Majority of plants consider that lightning-arresters do their work satisfactorily, but some plants experience the following troubles:

1. Generator current follows a discharge to ground.
2. Lightning jumps to water coil on transformers.
3. Arrester put out of order after each discharge.
4. When switching high-tension circuits, generator current follows discharge to ground.

130. *How are the grounds made for your lightning-arresters?*

The following methods are used for grounding lightning-arresters:

1. Copper plate about 30 in. sq. placed below water level in river bank; two strands of No. 4 copper wire attached to different points of plate by solder, plate is then covered with about 12 in. of coke or fine charcoal and then rest of hole filled with damp earth. In some cases plate is kept wet by means of a water-pipe.
2. Galvanized-iron pipe driven into ground about 18 feet.
3. Coils of copper wire buried in bank of river below water line.
4. Connected to steel flumes, steel structure, or feed-water pipe.
5. Connected to rails in cases of electric railway.
6. Connected to negative bus-bars.

X. CABLES.

131. *Have you any cables included in your transmission line?*

Only eight plants have cables in their transmission lines.

133. *Are they lead covered?*
136. *Do you prefer rubber or paper insulation, and why?*

All cables used are lead-covered. One plant in Class A has a three-phase submarine cable 4300 feet long, steel armored.

In most cases where cables have been installed recently paper insulation is used; the advantages claimed for paper-insulated cables are:

Cheaper and more durable: rubber insulation deteriorates in short time. One plant claims that there is less trouble from moisture with rubber.

137. *Give sketch of section of cable, showing arrangement and size of conductors and arrangement and thickness of insulation and sheath?*

(Sketches of various cables used are shown, see Figs. 22-25.)

138. *Are the conductors solid or stranded?*

Stranded cable is used almost entirely.

139. *Is the sheath lead? or lead and tin? and is it iron armored?*
140. *If lead and tin, what is the percentage of the latter?*

Cables in most cases are covered with a composition of lead and 3% of tin—the tin lessens corrosion.

143. *What means do you employ to protect cable sheaths from electrolysis?*

The cable sheaths are grounded to rails, gas-pipes, etc. as a protection against electrolysis.

144. *What protective devices have you for the cables, and do they prove effective and satisfactory?*

The majority of plants have lightning-arresters as a protection for their cables, also overload circuit-breakers in stations.

145. *Do you take any unusual precautions in operating to ensure the safety of your transmission cables?*

In most cases no unusual precautions are employed in operating to ensure the safety of transmission cables.

146. *What kinds of ducts do you employ for carrying your cables?*

The following are different kinds of ducts used for carrying cables:

Vitrified clay.
Cement-lined vitrified clay.
Creosoted wooden boxes.
Iron pipes (when cables run under water).

XI. OPERATION.

147. *Do you do your switching on the high- or the low-tension side of the transformers?*
148. *If the former, do you switch circuits when there is voltage on them but no current?*
149. *Do you switch high-tension circuits when loaded?*

Sixty-five per cent. of the plants do their switching both on low- and high-tension sides. In classes A and B in a great many plants switching is done on low-tension side only. In Class A, 50% of the plants do their switching on high-tension side only. The majority of plants make it a practice to switch their high-tension circuit with volt-

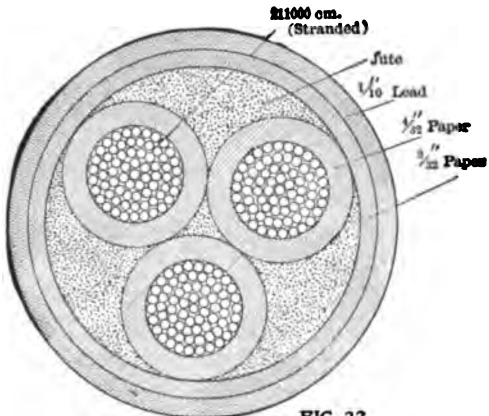


FIG. 22

4600 Volts

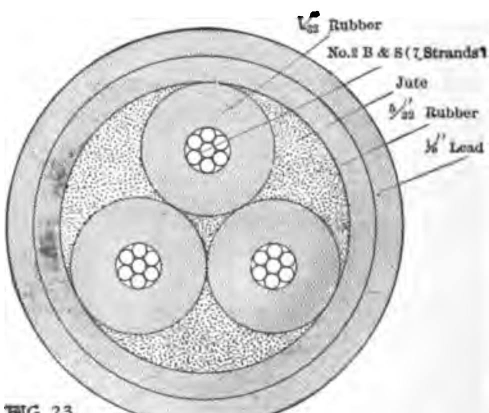


FIG. 23

25000 Volts

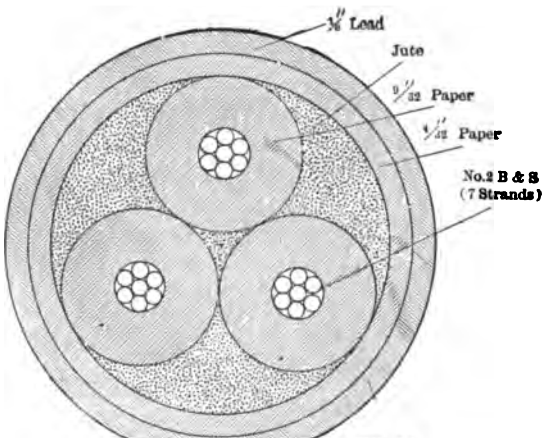


FIG. 24

26600 Volts

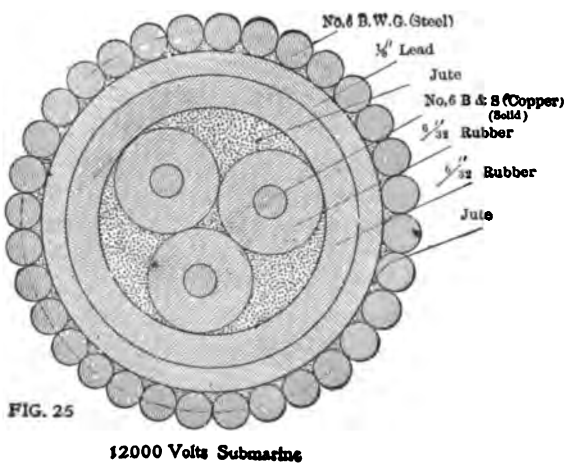


FIG. 25

12000 Volts Submarine

age on them, but no current. A number of plants, probably 40%, switch their high-tension circuits when loaded, and about 10% will do it only when it is absolutely necessary.

150. *What means for high-tension switching do you have?*

Following are the high-tension switches used in order of the quantity in use:

Oil-switches.
Fused-switches.
Air-switches.
Knife-switches (quick break).

Ram's horn: the horn is of ½-in. brass rod, curved and converging to a gap of about 10 in. In stations where there is any large amount of synchronous apparatus, this gap is spanned by a solid ½-in. rod set into suitable clips on the horns and provided with a suitable operating handle. In simple transformer stations the gap is spanned by a 1-in. porcelain rod having brass contact-pieces with binding screws for ordinary fuse-wire. These switches have been operated successfully on loads as large as 3000 kw.

151. *Is it satisfactory? If not, why?*

All plants claim their way of switching is satisfactory.

152. *Do yon have high-tension fuses, and if so, what type?*

The following kinds of high-tension fuses are in use:

Ball type.
Pole type.
Expulsion fuse.
D. & W. powder fuse.
Porcelain enclosed.
Glass enclosed.
Expulsion aluminum.
Sach's Noark.

154. *When you open a loaded high-tension main circuit with an air-break switch, do the lightning-arresters discharge?*

155. *If instead of an air-break switch an oil-break switch is used, does it have the same effect?*

In classes A, B, and C when loaded high-tension main circuits are opened with air-break switch, the lightning-arresters *do not* arc, but in classes D, E, and F they generally *do* discharge. But plants using oil-switches are not troubled to the same extent with their lightning-arresters discharging when they open a loaded high-tension main.

156. *Do you operate with grounded neutral? If so, why? If not, why not?*

A very small percentage of the plants operate with neutrals grounded.

157. *Have you ever had any trouble due to operating with grounded neutral either in your power circuits or because of trouble with neighboring power, telephone, or telegraph circuits?*

Yes; a number of plants operating with grounded neutrals affected telephone and telegraph circuits in the neighborhood. One company says if all the power of one of the large power stations be transmitted over

the whole length of the circuit with one wire of the transmission line open the telegraph companies are affected, but as this never occurred but for an instant once or twice it is not serious. We can still talk on our own telephone line with the sub-station carrying 500 kw., working with two transformers as above mentioned, and affect no neighboring power circuits, nor does it affect our own circuit on neighboring poles when running separate.

158. *Have you ever had one power-wire broken or one leg of the circuit open under a heavy load when the neutral was grounded?*
159. *Did this cause damage or trouble in any of your circuits or in other circuits, near or remote? If so, what?*

A few plants have had one power-wire broken or one leg of circuit open under a heavy load when the neutral was grounded, but in most cases no damage was done.

160. *Have you ever had trouble from the burning or charring of pins, cross-arms or poles due to the high-tension current?*
166. *What means have you taken to remedy the trouble and have the means proved effective?*

A great many plants have had trouble with burning of pins, cross-arms, or poles. In most cases this was due to continuous discharges, caused by:

1. Pin or insulator breaking; generally remedied by replacing pin or insulator.
2. Spray from falls freezing on insulator; remedied by moving line farther from falls discharging across insulator.
3. Bad insulator starting leaking to ground wire; remedied by moving ground wire from face of cross-arm.
4. Insulator with iron pin cracking and burning arm.
5. Pins burn, due to rain; remedied by replacing porcelain insulator with glass. In some cases discharge appeared to come from inner petticoat, in others through the porcelain and burning pin ½ in. from top.
6. Poor porcelain; remedied by replacing untreated oak pins with locust pins that have been boiled in paraffin and painted with P. & B. paint; also painted thread of insulator.
7, Gases from quartz mill forming film over surface of insulator.
8. Soot from passing trains being deposited on insulators; remedied by cleaning insulators and replacing pins.

In most cases discharge was worse in wet and foggy weather, and in many cases discharge took place in wet weather only.

167. *Have you had any trouble from insulators puncturing or current flashing around them?*

Only about 6% of the plants have had trouble from insulators puncturing or current flashing round.

168. *If the latter, what was the cause?*

The cause being either insulators damaged by stones or defective porcelain or glass, more often the latter.

169. *Do you have many insulators maliciously broken?*
170. *If so, what means have you taken to stop this, and with what success?*

A great many plants experience trouble from having their line insu-

lators maliciously broken. The following means have been taken to stop this:

1. By posting warnings.
2. Offering rewards for evidence that will enable them to locate and convict guilty persons.
3. Having watchmen along line.
4. Arrest and fining.

(Not much success with any of above methods.)

171. *Have you had any insulators break from internal strains when on the line?*

172. *Was this from actual strains in the glass or from improper placing upon the pin?*

Only a few plants have had insulators break from internal strains when on the line, the cause in most cases being the improper placing of insulator on pins.

173. *Have you ever had arcs start between your line wires?*

175. *Are you troubled from short circuits upon your lines? If so, what are the most serious causes?*

The following are causes for arcs being started between lines:

1. A piece of wire maliciously thrown across lines.
2. Branches of trees falling across lines.
3. High winds blowing wires together.
4. Large birds coming in contact with lines.
5. Broken insulators and pins.
6. Sleet storms.
7. Lightning discharges.
8. Generators ran away, due to sudden change in load.
9. Fields of generators demagnetized owing to armature reaction.

176. *Is your telephone system satisfactory?*

178. *Is there much more noise with a heavy current in the power-line than with a light current?*

Most plants claim that their telephones work satisfactorily; but a great number of plants complain that their telephones are more or less noisy in wet weather. One or two plants claim that telephones work better in wet weather, one of these plants belong to Class F.

Majority of plants claim that the amount of current in power-line does not affect their telephones. One plant says the heavier the load the less the noise in the telephones.

179. *Have you ever had any one hurt from the power voltage when using the telephone? If so, how did it happen?*

Only one accident recorded in connection with telephone; superintendent of power-house was killed at telephone. They think heavy sleet on power-wire made it sag until it touched telephone wire.

181. *Do you do work upon dead circuits when other circuits on the same pole-line are alive? If so, what precautions do you take?*

182. *Are such repairs made only in dry weather and in the daytime, or are they made at any time?*

Majority of plants do work upon dead circuits when other circuits on the same pole-line are live; the following precautions are taken:

1. Ground dead circuits.

2. Short circuit dead circuits.
3. Both ground and short circuit dead circuits.

In classes A and B where circuits are close together on cross-arms all circuits on same side of pole as dead circuit are made dead.

Majority of plants repair their lines at any time, day or night.

183. *How do you have your circuits patrolled and how often?*
184. *How much distance is one man able to patrol satisfactorily and over what kind of country?*

Lines are patrolled at different intervals of time ranging from once a day to five or six times a year, according to the kind of country passed through. Lines running by railway are often patrolled by men on a hand-car, lines cross-country by men on foot and on horseback. The amount of line that a man can patrol in one day varies with the kind of country: on level country ten miles; on hilly country from three to six miles. A man on horseback can do about 30 miles on level or about eight miles in mountainous country.

One company has a lineman and helper to look after 30 miles of line; they patrol line twice a week.

Another company has three men on hand-car who patrol 30 miles a day.

A number of plants do not have their lines patrolled regularly, but only when trouble occurs.

185. *What means are taken to compensate for capacity charging current of transmission lines?*

No special means are taken to compensate for capacity charging current of transmission lines by plants.

186. *Is voltage drop compensated for at receiving stations? If so, how?*
187. *Where there is more than one receiving station, what means, if any, are used for independently regulating the voltage desired by these stations?*

The various methods are used for compensating voltage drop at receiving stations:

A number of taps on transformers.
Regulators on secondary side of transformers.
Regulating heads on transformers.
Motor-driven potential regulators
Synchronous converters over-compounded.
Synchronous motors.

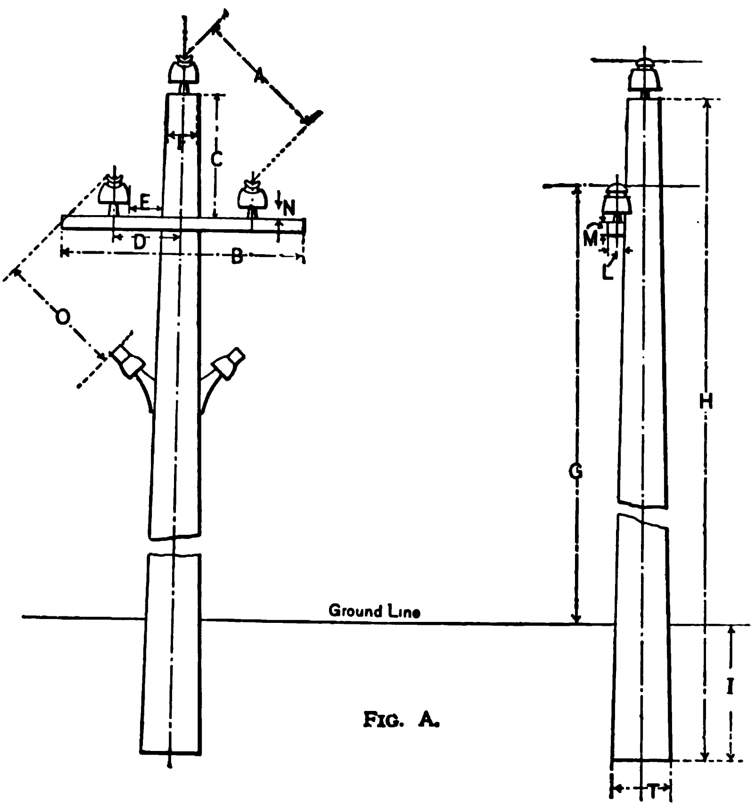


FIG. A.

Voltage.	A	B	C	D	E	F	G
16 000	18"	24"	16"	9"	—	6"	—
22 000	30"	68"	24"	15"	—	—	27'
22 000	30"	42"	26"	15"	8"	7"	15'
27 000	48"	64"	42"	24"	11"	12"	35'
30 000	40"	60"	23"	20"	12"	7"	20'2"
40 000	108"	120"	84"	54"	43½"	7"	19'6"
50 000	60"	72"	52"	30"	20¾"	7"	26'6"
50 000	78"	96"	67½"	39"	29"	10"	23'6"
45 000	42"	50"	36¾"	21"	10"	8"	27'8"

Voltage.	H	I	J	K	L	M	N	O
16 000	30'	5'	10"	—	4"	5"	2½"	48"
22 000	35'	6'	—	—	4"	4"	3"	120"
22 000	25'	4'	—	—	3½"	4½"	—	60"
27 000	45'	7'	17"	—	6"	6"	—	72"
30 000	22'3"	6'	—	—	3½"	4½"	—	72"
40 000	35'	5'6"	16"	—	5½"	3½"	10"	—
50 000	35'	5'6"	—	—	4¾"	4¾"	2½"	60"
50 000	35'	6'	14"	—	3¾"	5½"	1½"	72"
45 000	35'	5'6"	12"	—	5¾"	5¾"	2¾"	96"

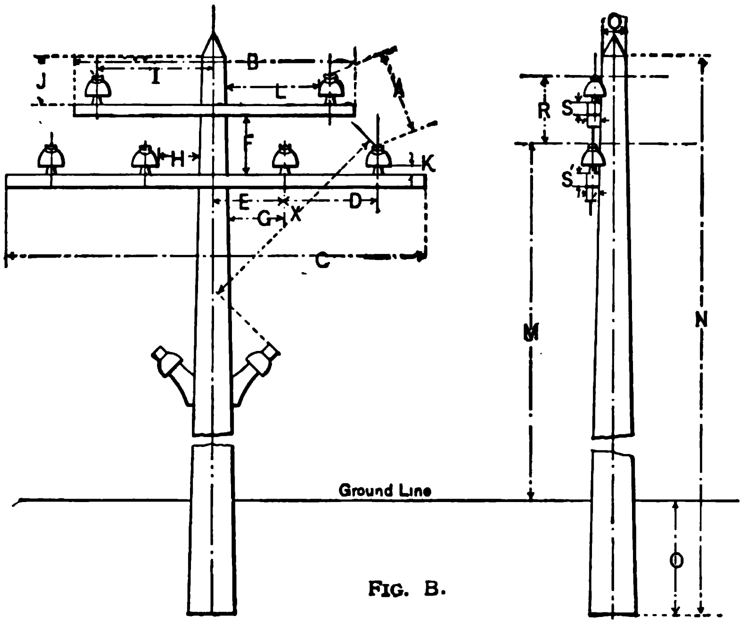


FIG. B.

Voltage.	A	B	C	D	E	F	G	H	I	J	K
12 000	24″	54″	72″	18″	14″	17½″	—	8″	23″	—	3″
11 000	20″	54″	72″	20″	12″	16″	8″	8″	22″	8″	4″
11 500	24″	60″	84″	24″	12″	20½″	9″	9″	24″	5″	2″
23 000	30″	72″	102″	30″	15″	26½″	—	8″	30″	8″	2½″
25 000	18″	60″	86″	24″	—	—	—	8″	22″	—	—
34 000	25½	62″	80″	18″	18″	20″	14″	—	27″	8″	3
30 000	30″	78″	108″	30″	18″	22″	9″	6″	33″	8″	4″

Voltage.	L	M	N	O	P	Q	R	S	T	S′	T′	X
12 000	17″	21′	30′	6′	—	—	22″	4½″	3½″	4½	3½	72″
11 000	—	—	35′	5′	18″	7″	—	4″	5″	4	5	96″
11 500	18″	—	24′	4′	—	6″	20½″	4½″	3½″	4½	3½	—
23 000	23″	23′	30′	5′	12″	7″	—	4½″	3½″	4½	3½	48″
25 000	—	30′	36′	6′	14″	7″	—	5″	4″	5	4	72″
34 000	19½″	—	35′	5′	12″	8″	24″	3½″	2½″	4½	3½	66″
30 000	24″	27′	36′	6′	16″	10″	26″	5″	4″	5	4	48″

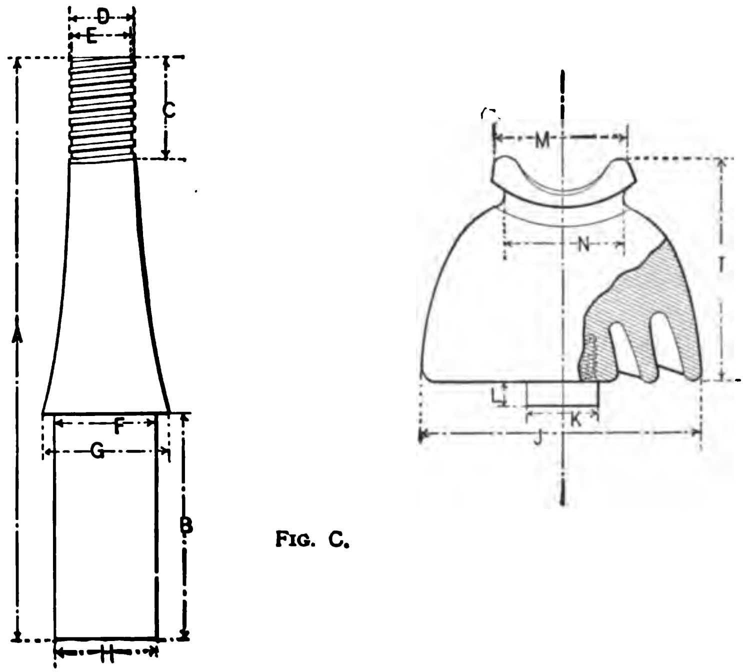


FIG. C.

Voltage.	A	B	C	D	E	F	G
12 000	11"	4½"	2"	1"	⅞"	1¼"	2"
4 600	9"	4"	2"	1"	¾"	1⅜"	1¾"
11 500	8½"	4"	2½"	1"	13/16"	1 7/16"	1 11/16
12 000	9"	4"	2"	1"	⅞"	1¼"	2¼"
16 000	10½"	4½"	2"	1"	⅞"	1⅜"	1¼"
20 000	10"	4½"	2⅝"	1"	⅞"	1⅜"	1⅞"
25 000	12"	4"	2¼"	1½"	1"	1⅜"	—
30 000	10"	4½"	2¼"	1"	⅞"	1 9/16"	2"
50 000	18⅝"	4⅞"	3¼"	1"	13/16"	2 7/16"	2 15/16"

Voltage.	H	I	J	K	L	M	N
12 000	1½	4"	5"	2¼"	⅛"	2½"	2¼"
4 600	1½	—	—	—	—	—	—
11 500	1⅝	4½"	5½"	2"	—	3⅜"	2 3/16"
12 000	1½	4½"	6"	1 5/16	3/16"	2½"	3"
16 000	1 15/32	4½"	6"	—	—	3"	—
20 000	1½	4"	5⅝"	2¼"	1¼"	2⅜"	2⅝"
25 000	1⅜	—	—	—	—	—	—
30 000	1½	5"	7"	2½"	—	3½"	2½"
50 000	2 7/16	9"	10"	4⅜"	3¾"	4⅝"	3⅝"

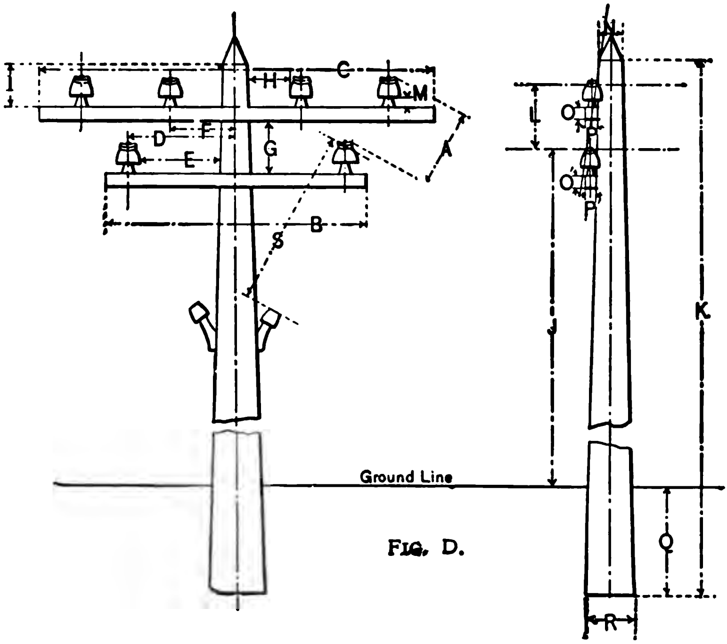


FIG. D.

Voltage.	A	B	C	D	E	F	G	H	I	J
12 000	24"	84"	84"	24"	17"	12"	16½"	5"	4"	32′
12 000	30"	72"	96"	29"	—	14"	21"	—	—	22′
15 000	30"	61"	96"	26½"	—	9"	27"	—	6"	32′
22 000	30"	68"	99"	—	30"	15"	24"	15"	9"	27′
24 000	36"	96"	132"	36"	—	18"	25½"	—	24"	25′

Voltage.	K	L	M	N	O	P	O′	P′	Q	R	S
12 000	39′8"	21"	3"	8"	4¾"	3¾"	4¾	3¾	6′	16"	54"
12 000	30′	26"	—	6"	4¼"	4¼"	4¼	4¼	5′	—	—
15 000	40′	31½"	—	7"	4½"	3½"	4½	3½	6′	16"	10′
22 000	35′	30"	—	6"	4"	4"	4	4	6′	—	120"
24 000	35′	31½"	—	8"	5¾"	5¾"	5¾	5¾	6′	14"	30"

For the Committee on High-Tension Transmission.

RALPH D. MERSHON,
Chairman.

Discussion on High-Tension Transmission Report.

J. H. Finney: Is not the spacing between wires given in Class E, in error? In the other classes the spacing seems to increase in direct ratio, but in Class E, for 31 300 volts, the spacing is only 31 inches. Is not this a mistake?

Ralph D. Mershon: The figures were examined carefully so as to prevent mistakes. There are not very many plants in this class, only four; so it depended on the choice of only four men to decide the average.

Peter Junkersfeld: Answer 5, Class A, on page 576 of the Committee's Report refers to the use of a ground-net of 0.25 inch steel cable suspended across the right of way and under power wires. This is of interest as it has been proposed by the Underwriters for insertion in the National Electric Code. It would be interesting to know the extent to which such ground-nets have been used and what degree of protection can safely be credited to them.

President Arnold: These nets are installed under high-pressure transmission lines in a number of places between Chicago and New York on lines parallelling the Lake Shore and the New York Central railroads, also between Chicago and Denver. They are in much more common use in Europe. We have just begun to use them; as a particular instance they may be found on the line of the Fonda, Johnstown, & Gloversville Railway.

L. Schuler: Ground-nets are used in Europe to a great extent, especially in Germany and Switzerland, as the authorities require them for a high-pressure line crossing a highway. It has been found, however, by experiment that in nearly all cases the wire, if broken, will, in consequence of its twist, jump over the side of the net. If a high-pressure line crosses a railroad, the authorities usually require a completely closed tunnel of iron work through which the line passes.

Ralph D. Mershon: The speaker has put in one or two of these ground-nets himself, but he does not think very much of them. They are generally put up as a matter of sentiment, as a protection in the event of lines coming down, especially from sleet. If it is feared that the lines will come down from sleet, then of course the netting has to be strong enough to carry any sleet that might collect on it. A netting could be put in strong enough to take care of any probable load of ice or snow, but that would mean a rather formidable sort of structure. Probably the best method of protecting lines liable to be crossed by high-pressure wires is, if possible, to put the poles of the crossing line on each side of the line crossed; have these poles close together, and so high that if the upper line breaks it cannot possibly reach the line crossed. Such construction is as near absolute protection to the lower line as you can get against anvthing short of the main line falling down sideways.

S. B. Storer: The Utica and Mohawk Valley Railroad Company have a short section of their line fitted with the netting underneath. This netting is made of two iron wires on either side of the cross-arm; these wires are twisted and at intervals of about six feet there are three-cornered sticks from one side to the other that are expected to hold the transmission line in case it breaks. The iron wires supporting these sticks are mounted on insulators of exactly the same type as used on the transmission line, so that even if one of the two transmission wires should break there is no tendency for it to ground. The speaker does not like this kind of construction, because he thinks the netting or cradle suspension should be permanently grounded. An iron cross-piece is preferable to a wooden cross-piece for the reason that in using synchronous motors or synchronous converters, one line might break and the two ends drop on this netting, and the machines would go on operating just as they were before. If this did happen, and the wooden cross-pieces were wet, they would carry the current to the iron span-wire thus completing the circuit through the cross-pieces and the iron wire. This would quickly burn the cross-pieces and the wires would drop down just the same as if no support were there. Perhaps it would be much better to have a strong iron netting underneath the transmission line and have the wires of such capacity as to carry a short circuit without burning off.

F. A. C. Perrine: At the National Electric Code meeting last year this subject was carefully discussed. The Underwriters were at first very strongly in favor of a netting, but the question just asked by Mr. Storer, whether the netting should or should not be grounded in any case, came up at once. It seems important that the netting should have at least as great carrying capacity as the transmission wire itself, otherwise the netting would burn off by reason of the wire grounding.

The second plan proposed by the Underwriters was the one mentioned by Mr. Mershon, that of setting the poles close enough together and elevating them to such a height that a break in the wire could not bring the transmission line in contact with any wire crossing underneath it.

There were, if the speaker remembers correctly, three methods accepted by the Underwriters: first, guard wires placed on the ends of the cross-arm carrying the telephone wires and above them so that the transmission line could not come in contact with the telephone line by breaking. This was the preferred method, and it was left to the discretion of the transmission company whether it would ground or insulate the guard-wires, it being considered that it would make very little difference which was done. The grounding of it would have a tendency to burn off the transmission line, but in either case the transmission line could not come in contact with the telegraph

or telephone wires. The other two methods were admitted as permissive. In the second method the transmission line would have to be raised the height of the street above the telegraph and telephone lines, so that in case of a break it would fall out of contact, which means that in a 60-foot street the transmission line would have to be 60 feet above the telegraph and telephone lines. The third method was the use of a grounded screen. In that case the screen should have more carrying capacity than the transmission line itself, so that in no case would the screen be burned through. All of these systems were recognized as being deficient, but after discussion lasting one day in which the National Electric Light Association, the Pacific Coast Transmission Committee, the INSTITUTE, and the Underwriters were involved, that was the best that could be gotten out of it.

The importance of this is very great, for there has been at least one instance of a transmission line falling across a long-distance telephone line and burning out all the instruments within many miles, and burning down a house. But it is questionable whether these guard-wires are sufficient protection. The speaker thinks there is not yet any very well-established experience.

EUGENE CLARK: Dr. Perrine has not mentioned one serious fault of any form of netting: the transmission span would generally be from 100 to 300 feet long at a crossing, and the netting under the line would necessarily be only a few feet wide. Under such conditions, a broken transmission line would probably curl up and fall off from the netting. Under such conditions, the netting would be useless unless thoroughly grounded.

S. B. STORER: The speaker understands that in Switzerland they make use of a ring projecting from the cross-arm through which each transmission wire passes; these rings are on both sides of the insulator so that if the wire breaks it will strike the ring before the ends touch the ground. These rings are grounded. Has any one here seen that construction, and does it afford protection?

W. B. JACKSON: It is used upon the Valtellina Road in Italy, where the high-pressure wires are equipped in this manner at each road crossing. Although the rings operate very satisfactorily in case of a break in the line, they sometimes give trouble when the lines do not break, and the engineers consequently found it desirable to have them cut out.

PRESIDENT ARNOLD: Why should the ring operate without the wire breaking?

W. B. JACKSON: They found that to give a sure grounding when the line broke they had to make the ring quite small or had to carry it a considerable distance out from the cross-arm, otherwise the wire might drop and not ground; but if they got it too small or too great a distance from the cross-arm there was danger of its becoming slightly displaced and thus causing a ground when such was not desired.

N. J. Neall: On page 389, rubber insulation is said to deteriorate in a short time. What is the relative depreciation in rubber cable?

James Lyman: Several cases have come to the speaker's notice of lead-covered, rubber-insulated, single-conductor cable, used for station wiring, where the rubber has deteriorated very rapidly, and broken down after only a few months' service. It is probable that in these cases a high static pressure was induced. The rubber seemed to be cut, and acted upon as if ozone had been present. In one case the cable was used on 13 200 volts pressure, 25 cycles; it was made to stand a working pressure of 30 000 volts, and breakdown pressure of 50 000 volts. After operation of about two months it went to pieces at different times, under normal operating conditions. There was no question regarding the good quality of the rubber insulation. There were six of eight different breakdowns at different times, thus indicating that they were not due to any defect in the cable itself. Another case came to the speaker's knowledge of a single, lead-covered, rubber-insulated cable, used on 13 200-volt, 60-cycle current, good for perhaps 20 000 volts—that broke down in the same way. For these reasons the speaker does not recommend the use of single-conductor, lead-covered cable, either on 25- or 60-cycle work, for station or outside wiring, where the pressure is above 5000 or 6000 volts; below that there is not much danger of the static dischage. The speaker knows of a number of cases where single-conductor, lead-covered cable is used on 6000 volts, and no trouble has been experienced.

GENERAL DISCUSSION ON HIGH-TENSION TRANSMISSION MATTERS.

W. G. CARLTON: Regarding the comparative reliability of overhead and underground lines, President Arnold and Mr. Wirt have both pronounced in favor of the overhead line. The speaker would like to hear something of the conditions under which President Arnold was considering this question; it seems that there are not very many cases where overhead lines can be the more reliable.

PRESIDENT ARNOLD: Of course it is not advisable to make a general statement that the overhead line is the more reliable and is always the line to install, because it is well known that in city work the use of underground or conduit is practically compulsory; in these circumstances it is unquestionably the more reliable because it is not subject to malicious interference, at least not to any such extent as an overhead line might be. When considering transmission lines, extending across country or through a region more or less settled—especially on private right of way—the speaker's conclusions are the same as those of his associates, that the overhead construction is preferable. It is preferable for two reasons: first, much less in first cost, and presumably in maintenance; secondly, it is much more accessible to repair in case of accident, because the trouble may be easily located and quickly repaired. These advantages do not obtain in the case of underground or conduit work. Any one that is installing electrical plants will admit that it is cheaper to construct overhead lines, and where these lines are permitted they are usually installed.

CHARLES F. SCOTT: President Arnold has said that underground wires are considerably more expensive to install than overhead wires. About what per cent. of the plant investment is represented by the transmission construction?

PRESIDENT ARNOLD:—Our case is one which would make the underground construction cost more in proportion to the overhead than in ordinary cases, for the reason that there are so few wires to carry, the maximum number being six and part of the way only three wires. In building this line we are running through rock almost all the way and will have to blast a large part of it. It is a case of digging and blasting a trench 57 miles long, so our preference for an overhead system is obvious.

PETER JUNKERSFELD: In replying to Mr. Scott's question, a comparison might be made with the high-pressure 25-cycle transmission systems in large cities, many of which represent from four to seven per cent. of the investment in the entire central station system. In the case in question the percentage would not be much higher, and probably is lower because of the heavy investment in car equipment, track construction, power-houses, and so on.

President Arnold: Perhaps it will be lower than that. The speaker cannot give an exact figure.

Ralph D. Mershon: A plant with which the speaker has been associated has a transmission line of about 17 miles in length. The pressure at the terminal station is 22 500 volts. The last 3600 feet of this line consists of four three-phase cables each 3600 feet long. This line has been in operation for about three years. During that time, so far as the speaker knows, there has not been any trouble with the cable, except once when a defective joint was at fault, due to bad workmanship when the cable was installed. This cable is protected by choke-coils and lightning-arresters at the terminal house where the overhead line enters it; and although there are on this transmission system two grounded wires for protection against lightning, yet lightning occasionally comes across the arresters. Some short pieces of the cable are used for wiring at the generating station, and have at times a pressure of 25 000 volts. The neutral point is grounded at the generating station only. In this installation the cable-bells are made of hard rubber, with leads brought up through hard-rubber tubes, the bells being filled with paraffin.

N. J. Neall: The allowance for depreciation of poles is, to-day, an important item in the fixed charges for a transmission line. It would therefore be interesting to know whether this statement as to life of various kinds of poles represents the depreciation as estimated by the various companies answering these questions, or the years they have used the different kinds of woods, or their opinion as to the relative values of different woods expressed in depreciation.

President Arnold: We can say offhand that very few maintain that a wooden pole will last for 15 years or even for 10 years. It is likely that the figures given in the report represent the life of a pole from a theoretical viewpoint. A pole may last for 10 or even for 15 years—subjected as it is to continuous attacks from the elements—but 15 years is assuredly the maximum limit.

Ralph D. Mershon: In his Introduction Mr. Carlton barely touched upon the question of the possibility of high-frequency pressure effects due to an unconfined arc from a defective cable. Will Mr. Carlton please refer to this matter now?

W. G. Carlton: Only one case of that kind has come to the speaker's attention. It happened in New York, and did considerable damage. In our experience in Chicago nothing of that kind has happened, but there is always a possibility of it happening.

Charles F. Scott: There is a station in New York, the Kingsbridge station, which has been operating for a year or two with open-air switches. It operates at 6600 volts, sometimes in parallel with the other power-houses.

W. G. CARLTON: This possibility of a rise in pressure in opening a high-pressure circuit in the air is generally conceded. A number of tests made here by Mr. Eastman have demonstrated it, and the results are decisive.

G. N. EASTMAN: The tests were made on a three-mile length of 2/0 three-conductor, paper-insulated, lead-covered cable with only the charging current of the cable. A static voltmeter was connected between one conductor of the cable and ground and an oil-switch and air-switch connected in series with the cable, so that they could be opened alternately. The oil-switch was so arranged that one break or a number of breaks in series could be made. The air-switch had but one break. By opening the air-switch very gradually, drawing out the arc, the rise in pressure was 40 to 50% above the normal. With the oil-switch no rise in pressure could be detected when the switch was opened having several breaks in series; with one break only a slight rise was detected when the switch was opened very slowly. These tests were duplicated, using the spark-gap instead of the static voltmeter, and the same indications were obtained. When the air-switch was opened, the charging current increased as the length of arc increased. By carefully drawing out the arc, a charging current seven times its original value could be obtained.

RALPH D. MERSHON: In his introduction Mr. Carlton seems to intimate that if a fire-proof cover were installed around a cable, thus confining the arc, there would be no oscillation; if the arc were not confined there probably would be oscillation. Has Mr. Carlton made any experiments that would justify this intimation?

G. N. EASTMAN: No; but the same conditions would prevail in the case of a short circuit as would obtain in the switch when opening under certain load conditions. From the results of experiments made by Dr. Steinmetz the speaker believes that he recommends the wrapping of cables in order to confine the arc.

RALPH D. MERSHON: Granting that a rupture of short circuit by oil might give very different results from an arc in air, it doesn't necessarily follow that you get in a confined arc the same results you would in oil. Has there been, so far as you know, any definite experiment tending to show pretty conclusively that cables protected in this way if they burn out are less likely to produce dangerous oscillatory effect than if they burn out in the air without this cover?

G. N. EASTMAN: So far as personal knowledge goes, no experiments have been made along this line, but the harmonic which is evidently obtained appears to depend upon the length of the arc. For instance, in all of the tests which were made in interrupting the charging current of the line, a certain length of arc would give a definite charging current, and an increase in the length of arc would give an increase in current.

H. B. ALVERSON: The speaker has witnessed tests of oil-switches with an ordinary steam-gauge put on the breaking chamber, the amounts of oil being varied from nothing up. In opening under oil the pressure varied from 50 lb. to 300 lb. depending on the point on the curve where it was broken, and an oscillograph in the circuit showed no pressure rise. With air only in the chamber, the air pressure would be from 10 lb. to 15 lb., while the oscillograph would give variations in which the pressure rise would go as high as twice normal pressure, the results being similar to opening arcs in air.

RALPH D. MERSHON: One would think that in a three-phase cable a short circuit would result in a definite length of arc determined by the distance between the conductors, and that there would not be much variation in the length of this arc. It seems to the speaker that unless definitive experiments are made with actual reference to the short-circuiting of cables—closed or open arcs—one could not draw satisfactory conclusions.

G. N. EASTMAN: We have had some short circuits happen between the conductor and ground, and the circuit-breaker at the station opened before the short-circuit had sufficient time to destroy the insulation between conductors. In one case where this occurred, the conductor on which the short-circuit was established was burned in two, but the insulation remained sufficiently high on the other two conductors of the cable to allow their being operated at the normal system pressure. This occurred on the 9000-volt system of the Chicago Edison Company in which the neutral was grounded, and the ground which occurred was a direct short circuit on one phase of the generators.

F. WOODMANSEE: The speaker was interested in making a test at Kalamazoo, a few years ago, to determine the effect on line due to the rupturing of the circuit by means of oil- and air-break switches. In that test it was found, in breaking a loaded circuit with an air-break switch, that surging occurred at instant of breaking the arc, but when rupturing the circuit by means of oil-switches there was practically no surging at all. These results were verified by spark-gaps connected across the line, as well as by means of an oscillograph.

The breaking of the circuit by means of allowing the arc to rise and break from what is known as a "goat-horn" was tried. On two occasions the light breeze extended the arc until it was about 33 feet long. At that instant it short circuited the load and reactance-coil, making a dead short-circuit on the system. On opening the switch there was a pressure rise on line of at least three or four times that of the operating pressure. This was verified by the spark-gaps. These tests demonstrated that the rupturing of high-pressure heavily-loaded or short circuits by means of air-break switches was dangerous, while they could be opened with safety by means of oil-switches without any very great rise in pressure.

RALPH D. MERSHON: Have any experiments been made with definite arc length? In opening an air-brake switch the practice is to start from zero arc and increase gradually until the maximum arc of this switch is reached; in doing this the length of arc may be struck that will give surprising results, results that might not be obtained with short arcs.

It seems to the speaker that Mr. Carlton's Introduction contains a timely reference to the very important subject of protecting cables from one another when one of them happens to fail. Now if the idea is simply to protect these cables from the heat of adjacent arcs it might be done by the scheme outlined by Mr. Carlton—the use of tile or brick—but if in addition we can, by asbestos wrapping, protect to a more or less extent against abnormally high pressure due to oscillatory effects, then it would seem that the protection by such wrapping were much to be preferred. Up to the present time, this discussion has failed to elicit any definite data as to the effects resulting from the burn-out of a cable,—the question naturally arises, will there necessarily be a higher pressure with the open air than with the enclosed arc?

F. WOODMANSEE: Regarding the first point raised by Mr. Mershon, an instrument was used to determine the length that the arc was drawn out. This instrument was used with both the air-break and oil-switches. The shorter the length of arc the less pronounced the surging effect.

W. G. CARLTON: Referring to Mr. Wirt's remarks, the asbestos wrapping would protect the cable from arcs due to adjoining cables; but in the case mentioned, the sheet-steel covering was used to confine the arc. If a high-pressure, three-conductor cable burns out and the circuit-breaker does not open the line, there will not be any cable or asbestos left where the arc is; in some cases three or four feet, or even more, of the cable has been entirely destroyed.

RALPH D. MERSHON: Of course if cables are laid on tile shelves and not wrapped or covered with the iron sheathes mentioned by Mr. Carlton, there would not be any confining of the arc. Now in order to avoid any dangerous effects from the arc—if the effects can be avoided by confining the arc—the arc would have to be confined in such a way as to develop a fair amount of pressure. If this were done, some precautions would have to be taken as to the strength of the encircling protection. In the case of asbestos-wrapped cable and a burn-out the speaker would like to know if any of the wrapping has been blown to pieces. Under some conditions there might be a considerable amount of pressure developed in asbestos-wrapped cable, enough, perhaps, to destroy the wrapping.

F. WOODMANSEE: In Mr. Wirt's paper no mention is made of the protection of underground cables by means of static dischargers. The protection referred to being from static accumulations on cables. It is a mooted question whether these static dischargers are useful or not; some engineers are of the

opinion that this kind of apparatus produces more trouble than it prevents.

PETER JUNKERSFELD: For several years we have believed that under our conditions in Chicago static dischargers are, as Mr. Woodmansee intimates, liable to be more troublesome than useful; for this reason we have never installed them. Formerly the pressure was 4500 volts, but during the last two years it has been 9000 volts on our transmission system.

G. N. EASTMAN: The Edison Company is operating a grounded system and the static arresters would have no effect on the system except in case of certain current effects; in that case the energy which the static arresters would be capable of taking care of would be so small that their value would be questionable.

F. WOODMANSEE: Are they not in use on the Manhattan system? Perhaps some one from New York could tell us how they are operating. In the West there are two places where they have been in service only a short time—in Kansas City and Minneapolis. There is some difference of opinion as to whether they are of any value, or whether they are really introducing a number of weak points in the system which would have more serious effects than the static pressure.

PETER JUNKERSFELD: The New York Edison Company, it seems, does not use static dischargers on their 6600-volt, 25-cycle system which is a higher pressure than our old 4500-volt transmission, nor do they ground the neutral. In Chicago, since raising the pressure to 9000 volts, we have grounded the neutral.

H. B. ALVERSON: Referring to static dischargers, we have a system of between 40 and 50 miles of 11 000-volt cables and have no static dischargers. In about eight years' experience there have been but two instances where static dischargers might have been a possible benefit; that is, more than one cable giving out at the same time for the same cause.

CHARLES F SCOTT: Mr. Buck, of the Niagara Power Company, has said that he did not use static dischargers on the Niagara system and did not think it worth while; that he thought best to leave out as many of the safety devices as possible, as a safety device was apt to give more trouble than it prevented.

G. R. RADLEY: In Milwaukee static dischargers are used because the ozone had apparently formed an acid at certain places in the rubber cable, and at the hard-rubber bushings in several switches. Since installing them this effect has not been noticed, but since the neutral of the generators was grounded about the same time it may not be fair to give the credit entirely to the dischargers.

G. N. EASTMAN: On a system which is operated without a ground static arresters may be of some value. In one case with which the speaker is familiar, five miles of rubber-insulated, lead-covered cable was used, and many cases of trouble occurred. Lightning-arresters were installed and no benefit was noticed, but when the neutral was grounded the trouble disappeared.

A paper presented at the 192d Meeting of the American Institute of Electrical Engineers New York, Dec. 23, 1904.

THE MAXIMUM DISTANCE TO WHICH POWER CAN BE ECONOMICALLY TRANSMITTED.

BY RALPH D. MERSHON.

As transmission voltages, actual or proposed, become higher and higher and transmission distances reach out farther and farther, it is interesting and profitable to inquire into the probable maximum distance to which power will be commercially transmitted. As with most engineering enterprises, the limitations will come through economic conditions, and the greatest distance to which power will ever be commercially transmitted is the greatest distance to which it can ever be economically (using the word in its broad sense) transmitted.

In endeavoring to make such a forecast, as will be here attempted, it should be borne in mind that each additional limitation consequent upon the assumptions necessary in order to obtain definite representative figures adds to the chance of the forecast proving erroneous. For instance, the first asumption which must be made is that in the future power will be transmitted in the same way as now. This may not hold. There may be devised some other and better way not involving the use of transmission lines. Such, however, does not appear probable. Other assumptions as to methods of construction being the same as, or similar to, those at present in use may be eventually so modified by skill and experience as to change very materially any conclusions arrived at now. This is less improbable. Conditions, industrial and financial, may so change that the constants now assumed as fixing costs, interest, etc., will be materially modified. This is probable. Finally, it is certain that with the course of

time the value of power will increase, and this will materially alter any figures at which we may now arrive. The present conditions of practice and possibility are sufficiently definite, however, to warrant a forecast with the expectation that it will be applicable, approximately at least, for some considerable time to come. At any rate, the mode of treatment of the subject herein adopted will apply so long as present methods of power transmission obtain, and, with suitable changes in the values of the constants involved, afford at any time a means of obtaining a comprehensive view of the possibilites of long-distance transmission.

The elements which, in the broadest sense, limit the distance to which power can be economically transmitted, are two; the cost of power at the generating station, and the price which can be obtained for the delivered power. The difference between these two elements must cover the cost of transmission, the interest on the investment, and the profit. The cost of transmission comprises the loss of power n transmission, the cost of operating, and the cost of maintenance and repair. The value of the sum total of the interest which must be paid upon the investment, and the minimum profit which is considered satisfactory, will have much weight in determining the limiting distance of transmission. The less this sum is the farther power can be transmitted; a low interest rate and a low rate of dividend will, therefore, be conducive to long transmissions.

Let us consider in a general way the manner in which the investment in a transmission plant and the annual charges and expenses in connection with the plant vary with different outputs, voltages, and distances of transmission. For a given voltage, drop, and distance of transmission, the cost of all the apparatus and equipment, except the line conductors, will increase more slowly than the output of the plant. That is, the greater the output of the plant the less the cost per kilowatt of all the equipment, except the line conductors. This will be true of the operating expenses also. Therefore, since the interest charges and the charges for depreciation and repair are dependent upon the investment, the greater the output of the plant the less will be the quantities going to make up the annual cost per kilowatt of transmitting power, except those depending upon the line conductors. Since the weight of the line conductors, under the conditions assumed, will vary directly as the amount of power transmitted, those elements of the annual cost per kilowatt depending upon the line conductors

will be practically constant for all amounts of power transmitted and cannot be materially reduced by increasing the amount of power transmitted. With the same voltage, economic drop, and output, the elements of annual cost per kilowatt due to the line structure (pole line) and to its extent (patrolling, etc.), will increase directly as the distance. But, as outlined above, any increase of cost in line structure due to increase in distance can be offset by increase of output. On the other hand, the weight of the line conductors increases as the distance (for the same *economic* drop) and the elements of annual cost per kilowatt due to the weight of the line conductors will, therefore, increase as the distance, no matter what the output.

It appears, therefore, that all the elements in the annual cost per kilowatt for transmitting power, except those dependent upon the line conductors, may be continually reduced by increasing the amount of power to be transmitted. The annual cost per kilowatt due to the line conductors cannot be so reduced. It can be diminished only by such other means as will reduce the first cost of the conductors. As the first cost of the line conductors can be reduced only by increasing the voltage of transmission and as there is a limit to which such increase can be carried, it follows that *the limiting distance to which power can be economically transmitted will depend, finally, upon the cost of the line conductors and upon this alone.*

The limit of voltage referred to is not necessarily that due to physical considerations, such as difficulties of construction, air losses between conductors, etc.; for, leaving such matters out of consideration, it is easy to imagine the voltage carried to such a high value as will reduce the line conductors to the point where the increased cost of transformers and insulators, due to a further increase of voltage, will overbalance the saving in the line conductors, due to such further increase.

It will somewhat simplify the treatment of the subject if the interest charge be included as a part of the cost of transmission, and profits be represented by a percentage on the investment. This course will, therefore, be pursued. That is, it will be assumed that in the cost of transmission is included the interest on the investment (bond interest) and that over and above this cost there must be earned a certain percentage, which percentage will represent profits (stock dividends). In addition the following assumptions will be made:

Power purchased at low-tension bus-bars of step-up transformers and sold at outgoing bus-bars of the step-down station.

Frequency of transmission not less than 25 cycles nor more than 30 cycles as being the limiting frequencies which, while favorable to the transmission of power, are yet suitable for almost all purposes to which power can be applied.

Idle synchronous motors at step-down station to correct for power-factor, the average power-factor of the line being held as near unity as possible. In the plants of large output dealt with below, the possible approximation to unity power-factor will, in spite of the line-charging current, be sufficiently close, for practical purposes, to justify the assumption of unity power-factor.

That no matter what the capacity of the plant, there will be three transmission circuits, each upon its own pole line, and each capable of carrying one third the load.

That the power-factor of the load supplied will be 0.8.

That no matter what the size of the plant the number of transforming units at each end of the line be 18, each transformer being normally worked at $\frac{5}{6}$ of its rated capacity, so that one bank of three may be cut out, if need be.

That no matter what the size of the plant the number of corrective synchronous motors will be six, each being worked at $\frac{5}{6}$ of its rated capacity. The kilovolt-ampere capacity of these synchronous motors must, for a load power-factor of 0.8, be equal to $\frac{3}{4}$ of the kilowatt capacity of the load carried by the plant.

It is evident that the number of units must be considered as the same for plants of all capacities in order to take full advantage of the decrease of cost per kilowatt, due to increase of capacity.

The pole lines will be assumed as constructed with 12 steel towers to the mile.

Ideal conditions will be assumed throughout consistent with delivering reliable and cheap power. Since the object is to determine the *maximum* distance, the factors fixing commercial costs of apparatus will be taken at the lowest values likely to obtain.

Later on in this paper general equations are derived expressing the relations between the distance of transmission and the quantities which govern it. By making assumptions, in addition to those mentioned above, as to the values of the

various coefficients in the general equations and as to the purchase price and selling price of power, the curves of Figs. 1, 2, 3, 4, 5, and 6 have been obtained which are given and discussed here instead of at the end of the paper.

Fig. 1 shows the relation between the distances of tranmission, D, and the economical voltage, E, for different kilowatt outputs, W; that is, it shows the voltage which it is most economical to use

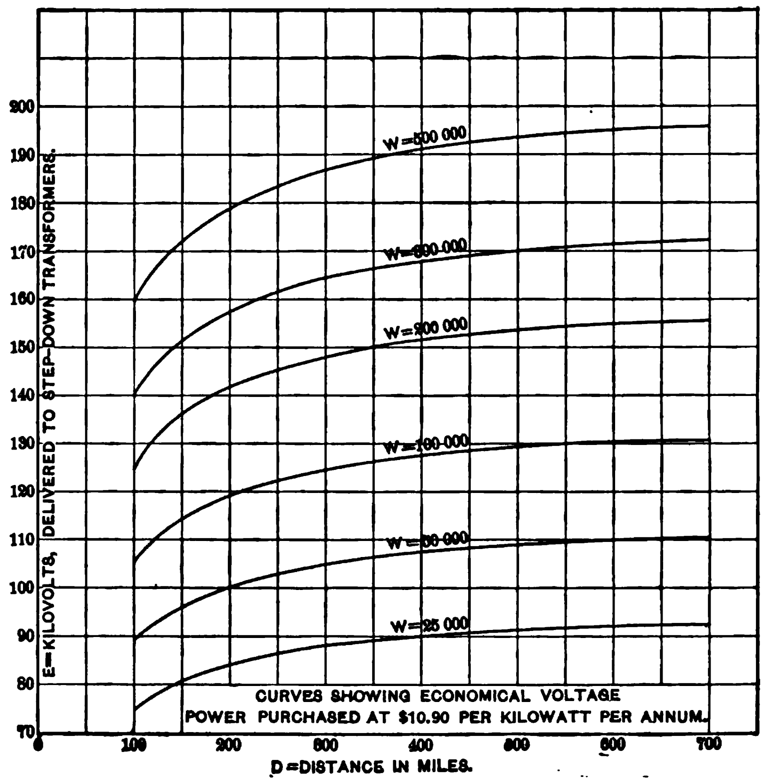


FIG. 1.

for any given output and distance of transmission.

Fig. 2 shows, in a corresponding manner, the economical drop.

Fig. 3 shows the diameter of the conductors corresponding to the conditions of Figs. 1 and 2.

Fig. 4 shows the relation between D, the distance of transmission, and p, the percentage net profit on the investment for

different values of output W and for selling price of $34 per kilowatt per annum.

Fig. 5 is similar to Fig. 4 but applies to a selling price of $20 per kilowatt per annum.

Fig. 6 shows for different selling prices the relation between

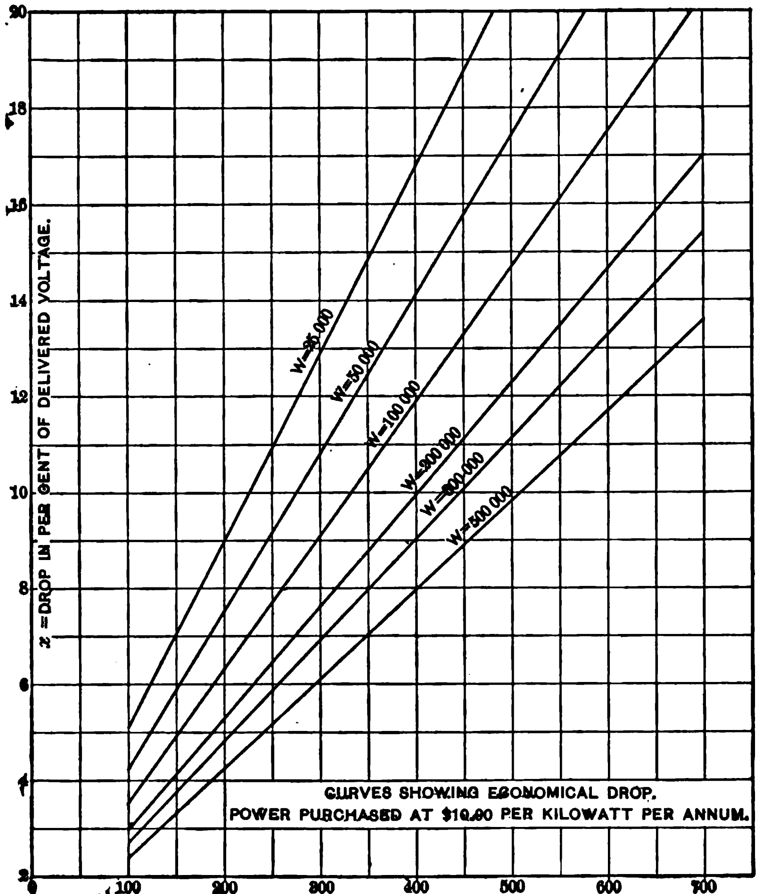


FIG. 2

the distance of transmission and the output for a net profit of 12%. The lower curve of Fig. 6 is derived from Fig. 4 by plotting the distances and outputs of Fig. 4 corresponding to a net profit of 12%. In a similar manner the upper curve of Fig. 6 is obtained from Fig. 5. The other curves of Fig. 6 were ob-

tained from other sets of curves (not included herein), similar to those of Fig. 4 and Fig. 5, and applying to the other prices of power to which Fig. 6 applies.

In obtaining these curves the constants have all been given

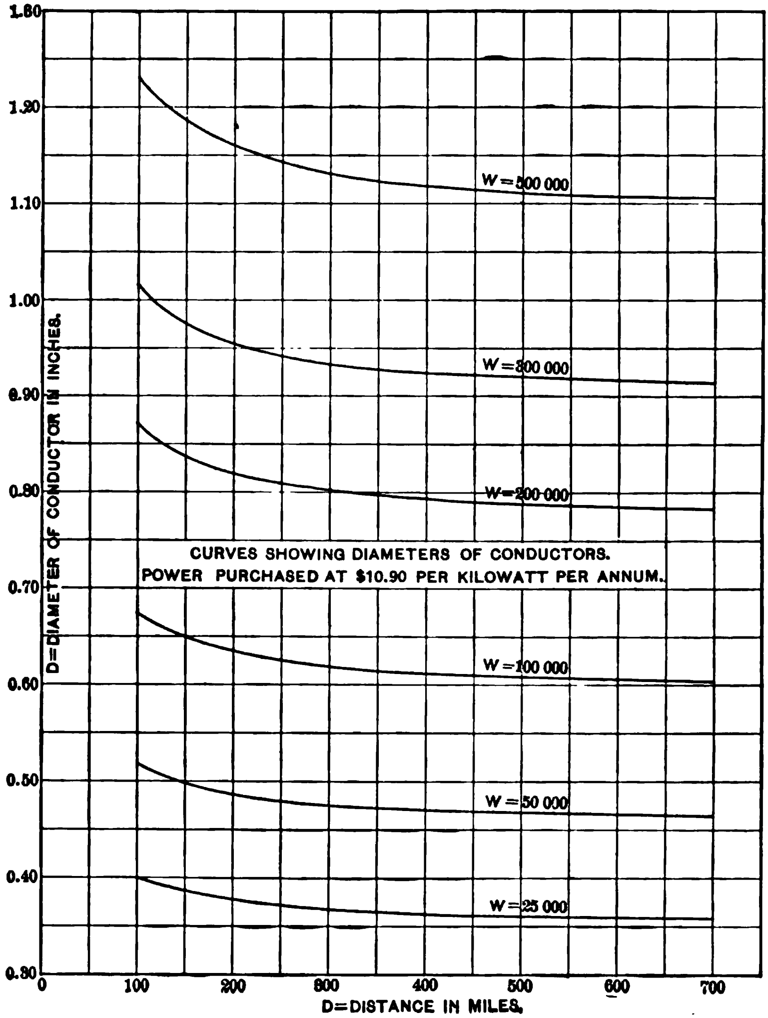


FIG. 3.

values favorable to long transmission distances. The costs have been taken lower than those ordinarily current in the endeavor to anticipate somewhat possible future prices. Also, the cost of power purchased at the step-up station has been fixed

at the very low figure of $10.90 per kilowatt per annum. These facts should be carefully borne in mind in considering the curves, which will all be more or less modified by changes in the quantities mentioned.

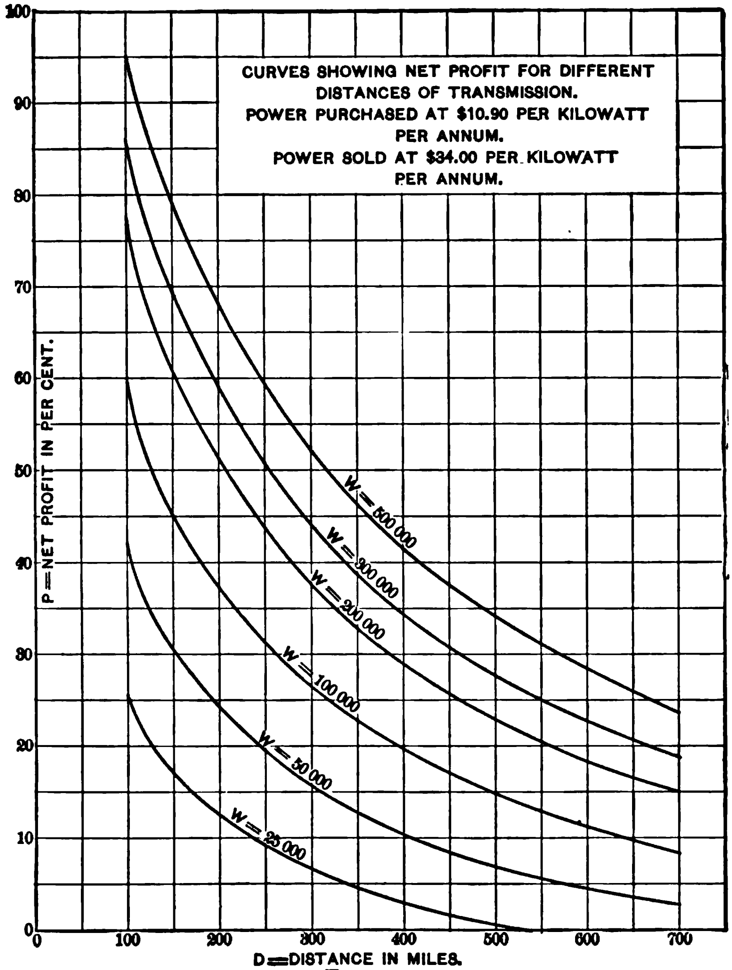


Fig. 4.

On comparing the diameters of conductors given by Fig. 3 and the voltages to which they correspond with the values of diameter and critical voltage given by Professor Harris J. Ryan in his splendid paper on that subject,* it appears that the diameters of Fig. 3 are considerably above those of the paper men-

* See paper read by Professor Ryan before American Institute of Electrical Engineers, February 26, 1904.

tioned. The values of Fig. 3 are affected by the price paid for power at the step-up transformers, but if this be taken even as high as $20 per kilowatt per annum instead of $10.90, the diameters of the conductors remain below those for the critical voltages. It appears, therefore, in the light of present knowledge, that the limit of voltage will come through economic conditions and not through conditions depending upon atmospheric losses.

It is difficult to fix upon a figure for the selling price of the delivered power which shall be representative. Power prices are so dependent upon conditions, especially those arising from the location and magnitude of the market and of the supply, that any figure chosen will be objected to by some as too high and

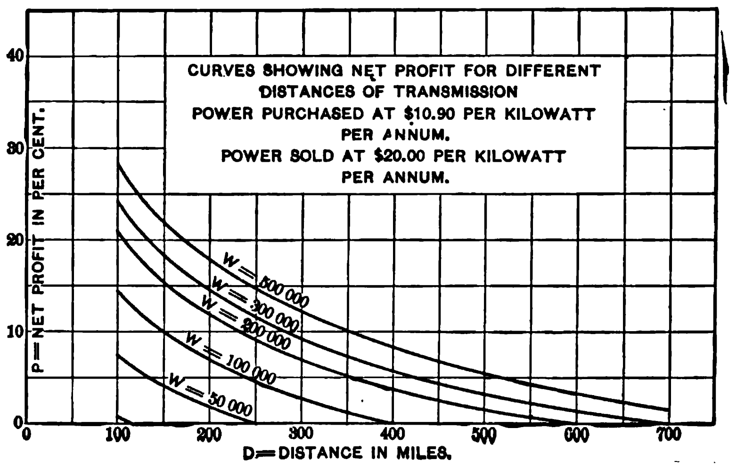


FIG. 5.

by others as too low. The same statement applies to the price assumed as that paid for power at the step-up station, but in a lesser degree. The selling prices of $34 and $20 have been chosen as the upper and lower limits for the price of power in such large amounts as are under consideration.* While it is unquestionably true that in some parts of the country power is worth, and will bring, much more than $34, the markets where such prices are obtainable are not very large; in the East, where large markets are possible, much more than $34 cannot be expected for very large amounts of power.

* The paper as originally presented contained curves applying to the selling price of $34.00 only.

On the other hand, $20 is believed to be as low as will obtain under any other than the most exceptionable circumstances. Fig. 6 covers this range of prices, giving curves for intermediate prices as well as the limiting prices mentioned.

The voltages to which the curves apply are much higher than those now in use commercially, but they are not beyond the range of future possibility. Manufacturers will now undertake commercial transformers for voltages as high as 150 000

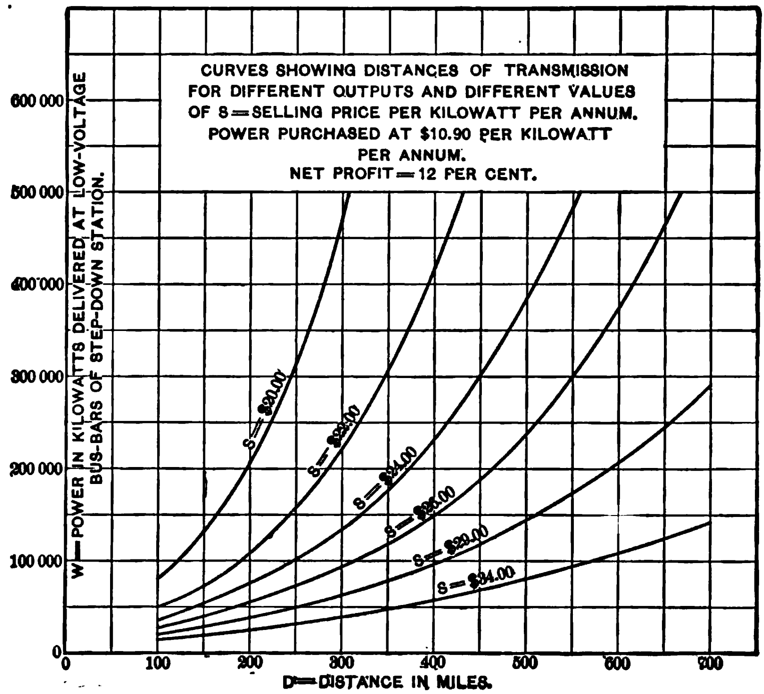


FIG. 6.

volts, and there is little question that when the demand shall come for units of the large capacities contemplated herein, the voltage requirements will be met. Such transformers will be structures of sufficient size to permit of being gotten at and worked upon from the inside as well as the outside and this, in connection with the fact that more space may be utilized for insulation, will render construction for high voltages much less difficult than at present.

The maximum amount of power dealt with herein, 500 000 kilowatts, is probably too high to be seriously considered at this time, but from 200 000 to 300 000 kilowatts is believed to be within the range of immediate future possibility. In a plant of this size it is probable that a net profit of 12% would be required, not alone for the purpose of dividends, but also as a protection to the bonds. A price of $26 per kilowatt per annum is probably a fair price to assume for the delivered power in such large quantities as are contemplated. Under these conditions Fig. 5 shows the distance of transmission to vary from 463 miles for 200 000 kilowatts to 552 miles for 300 000 kilowatts. For the present outlook, therefore, the limiting distance may be taken as about 500 miles.

It appears from the preceding matter that under the conditions assumed, the limiting distance of transmission will, for some time at least, be in the neighborhood of 500 miles.

It also appears that voltage limits will be fixed, not by conditions depending upon atmospheric losses, but by economic conditions.

The latter conclusion, while recognized as a possibility when this paper was begun, was unexpected. It is, perhaps, of greater present importance than the original object of the paper as conveyed in the title.

* * * * * * * * * *

The analysis on which depends the general equations from which the preceding curves were obtained will now be taken up.

Let E = voltage, in kilovolts, delivered to step-down transformers.

D = distance of transmission in miles.

x = percentage of power lost in the line in terms of delivered power.

e = efficiency of the whole system.

e_1 = combined efficiency of step-up and step-down transformers and synchronous motors.

d = diameter of line conductors in inches.

W = power, in kilowatts, delivered at low-voltage bus-bars of step-down station.

c = cost, in dollars per kilowatt per annum of power purchased at the low-voltage bus-bars of the step-up transformers.

Let s = price, in dollars, received for power per kilowatt per annum at the low-voltage bus-bars of the step-down station.

h = a quantity which, multiplied by c, will give the cost at the high-voltage terminals of step-up transformers.

R = total interest maintenance and depreciation charge per annum.

L = cost of labor for operating transformer stations and for executive and clerical services.

M = total investment.

C = total cost per annum of power delivered, inclusive of interest.

p = a percentage covering profit.

$$\therefore \quad e = \frac{e_1}{1+x}, \text{ since } \frac{1}{1+x} \text{ is the efficiency of the line.}$$

$$\therefore \quad \frac{Wc}{e} = \frac{Wc\,(1+x)}{e_1} = \text{total amount expended per annum for}$$

power purchased.

$\therefore \quad Ws$ = total amount received per annum for power.

$$\therefore \quad C = \frac{Wc}{e} + L + R$$

$$\therefore p = \frac{Ws - C}{M} = \frac{Ws - \frac{Wc}{e} - L - R}{M} = \frac{Ws - \frac{Wc\,(1+x)}{e_1} - L - R}{M} = \frac{N}{M} \tag{1}$$

Now M is made up of

(1) Cost of transformers.

(2) Cost of transformer switchboard apparatus, cables, lightning protection, etc.

(3) Cost of building and real estate.

(4) Cost of insulators.

(5) Cost of pole-line material and construction.

(6) Cost of right of way.

(7) Cost of corrective synchronous motors and exciters.

(8) Cost of switchboard apparatus, cables, etc., for synchronous motors.

(9) Cost of line conductors.

Cost of transformers will depend upon voltage and output

$f_1\,(E,W)$

Cost of transformer cables and controlling apparatus will depend upon same quantities as transformers, but in a different way;

$f_2\,(E,W)$

Cost of building will depend upon output;

$f_3 (W)$

Cost of insulators will depend upon voltage, diameter of conductors and number required; *i.e.*, voltage, diameter of conductor, and distance of transmission;

$f_4 (E, d, D)$

Cost of pole-line construction will depend upon diameter of the conductors and the distance. But the diameter of the conductors depends upon voltage, drop, output, and distance; hence,

$f_5 (d, D) = f_5 (E, W, x, D)$

Cost of right of way will depend upon distance only;

$f_6 (D)$

Cost of synchronous motors will depend upon output only, since all other elements affecting cost will be fixed;

$f_7 (W)$

Cost of switchboards and cables for synchronous motors will depend upon output only;

$f_8 (W)$

Cost of line conductors will depend upon voltage, output, line loss allowed, and distance of transmission;

$f_9 (E, W, x, D)$

The sum of these nine functions constitutes M, the total investment.

Now R, the total interest and depreciation charge, depends upon all of the several quantities making up M.

In what follows the numerical values of the constants are those taken for the specific problem treated herein.

Let $p_1 = 0.125$, being the percentage of transformer cost for interest, depreciation, and repairs.

$p_2 = 0.125$, being the percentage of transformer switchboards cost for interest, depreciation, and repairs.

$p_3 = 0.075$, being the percentage of buildings cost for interest, depreciation, and repairs.

$p_4 = 0.10$, being the percentage of insulator cost for interest, depreciation, and repairs.

$p_5 = 0.125$, being the percentage of pole line cost for interest, depreciation, and repairs.

$p_6 = 0.05$, being the percentage of cost of right of way, for interest only.

$p_7 = 0.125$, being the percentage of synchronous motor cost for interest, depreciation, and repairs.

$p_8 = 0.125$, being the percentage of cost of synchronous motor,

switchboard, etc., for interest, depreciation, and repairs.

p_9 = 0.05, being the percentage of cost of conductors, for interest.

R = the sum of these percentages multiplied respectively into the several quantities to which they refer

L depends upon output only

$$f_{10}(W)$$

The numerical values given for the percentages p_1, p_2, etc., are those which will be used in the specific problem herein treated. The rate of interest has in all cases been taken as 0.05, so that by subtracting this from the above values the depreciation assumed in each case may be determined.

If there be substituted in equation (1) the values of M, L, and R, as expressed by the above symbols, there will result an equation expressing in the most general terms the relations between the distance of transmission and the quantities which govern it. This substitution results in rather an unwieldy expression and will be omitted.

Before proceeding with the determination of the forms of the several functions indicated, it will be necessary to enter into a discussion of the relations existing between voltage and line loss, and the quantities governing them respectively.

Let q = that portion of the cost per kilowatt at the low-tension bus-bars of the step-down station, which is due to line loss and to interest on the value of the conductors; then, anticipating in part the matter of a few pages further on

$$q = \frac{p_9 K_9 \dfrac{W D^2}{E^2 x} + hc\, Wx}{W}$$

in which $p_9 K_9 \dfrac{W D^2}{E^2 x}$ is the interest on the conductors and $hc\, Wx$ the cost of the power lost in the line.

Setting the first derivative of this with respect to x equal to zero, in order to determine the value of x corresponding to the minimum value of q, we find the well known expression for economic drop

$$x = \left(\frac{p_9 K_9}{hc}\right)^{\frac{1}{2}} \frac{D}{E} = n\frac{D}{E} = 0.038\frac{D}{E} \qquad (2)$$

From this equation for x we may obtain the equation

$$p_9 K_9 \frac{D^2}{E^2\,x} = hcx$$

But the first member of this equation is the interest on the line conductors per kilowatt delivered, and the second member is the annual cost of the line loss per kilowatt delivered. That is, for the most economical conditions the line loss per kilowatt delivered must be equal in value to the interest on the conductors per kilowatt delivered—a relation already well known.

As has already been suggested, there will be a limit to which the voltage can be carried, due to the fact that, although increase of voltage will diminish the annual cost of lost power and of conductors, it will increase the annual cost of certain other important factors. The elements of annual cost which are affected by change of voltage are the interest and depreciation of the transformers, the interest on the line conductors, the line loss, and the interest and depreciation of the insulators. The first and last items will increase with the voltage, because of the increased first cost, due to the increase of voltage; the other two will diminish.

Let q_1 = that portion of the annual cost per kilowatt of delivered power due to the line loss, conductors, insulators, and transformers. It has just been shown that for best economy the line loss and annual conductor cost must be equal, so that twice the line loss, $2\,hc\,Wx$, may be taken as representing the sum of the annual cost due to line loss and to the conductors. As will be shown later, the cost of the insulators will vary as the distance of transmission, and as the cube of the voltage and the cost of the transformers may be represented by

$$K_1'\,(E+K_1'')\,W^{\frac{3}{4}}$$

Hence remembering that p_1 and p_4 are the interest and depreciation of transformers and insulators, respectively,

$$q_1 = \frac{2\,hc\,W\,x + p_4\,K_4\,E^3\,(1+x)^3 D + p_1\,K_1'\,(E+K_1'')W^{\frac{3}{4}}}{W}$$

or, putting in the value of $x = \left(\frac{p_9\,K_9}{hc}\right)^{\frac{1}{2}} \frac{D}{E} = n\,\frac{D}{E}$.

$$q_1 = \frac{2\,hcn\,WDE^{-1} + p_4\,K_4\,E^3(1+n\,DE^{-1})^3\,D + p_1 K_1'(E+K_1'')W^{\frac{3}{4}}}{W}.$$

Now if the first derivative of q_1 with respect to E be set equal to zero to determine the best value of E, there results a quartic equation more interesting than valuable, so far as the present purpose is concerned. It will greatly simplify matters if instead of substituting the value of x in $(1+x)^3$ we substitute for x, x_1, a fixed drop of such value as will correspond to the average cost of insulator between the two extreme values of x which will be met with in practice; as will be shown later, the error due to such a course will be small. Hence

$$q_1 = \frac{2\,hcn\,W\,D\,E^{-1} + p_4\,K_4\,E^3\,(1+x_1)^3\,D + p_1\,K_1'\,(E+K_1'')W^{\frac{1}{2}}}{W}.$$

Setting the first derivative of this equation equal to zero, solving and substituting the value $n = \left(\frac{p_9\,K_9}{h\,c}\right)^{\frac{1}{2}}$ there results

$$E = \left(\frac{-p_1K_1'W^{\frac{1}{2}}}{6p_4K_4(1+x_1)^3 D} + \sqrt{\frac{p_1^2\,K_1'^2\,W}{36p_4^2K_4^2(1+x_1)^6D^2} + \frac{2\,(hcp_9K_9)^{\frac{1}{2}}\,W}{3p_4K_4(1+x_1)^3}}\right)^{\frac{1}{2}}$$

$$= \left(-\,3066\frac{W^{\frac{1}{2}}}{D} + \sqrt{9400356\;\frac{W}{D^2} + 3438.5\;W}\right)^{\frac{1}{2}} \qquad (3.)$$

This shows that the voltage may be increased with increase of output, which was to be expected since those costs which limit the voltage will diminish in their amount per kilowatt as the output increases. The value of x_1 used in the above equation was determined upon as follows: The minimum percentage drop which is ever likely to obtain is, say, 2.2; the maximum is, say, 11.5. The reason for selecting these values will be apparent on considering the values of E calculated from the above equation, and given below, in connection with the values of W to which they correspond, and the respective distances to which in each case the various amounts of power would probably be transmitted. The intermediate value of drop which will give the average insulator cost is 6.45%, and this value of x_1 is taken. With this value of x_1 the maximum error in insulator cost, between the limits assigned, will have place when x = 2.2 and x = 11.5. The percentage error at either of these limits is about 13%. But, as appears in the solution of the first derivative, at the point of minimum of the variables affected by the voltage the com-

bined values of the annual cost due to the conductors, the annual cost of the line loss, and that portion of the annual transformer cost due to voltage, is more than three times that due to the insulators. The total variable quantity involved, therefore, is more than four times the annual cost due to insulators, and the error as a percentage of the total of values of the variables involved is less than $\frac{13}{4} = 3.25$, instead of 13%. As will be seen on examining the manner in which x_1 enters the equation for E, the maximum error in E will be less than 3%, also which will to a like extent affect the values of x. This error is negligible so far as the main problem is concerned, and indeed so far as the question of voltage itself is concerned.

In Fig. 1 are shown curves plotted from equation (3). These curves show the kilovolts E for different distances D, and different outputs W. Fig. 2 gives curves plotted from equation (2), using the values obtained from the curves of Fig. 1. The curves of Fig. 2 show the percentage drop x for different distances D, and different outputs W. In Fig. 3 are curves showing the diameters of the conductors for the conditions of Figs. 1 and 2. These diameters were calculated from the formula

$$d = k'_5 \left(\frac{W D}{E^2 x}\right)^{\frac{1}{2}} = k'_5 \left(\frac{W D}{E^2} \cdot \frac{E}{n D}\right)^{\frac{1}{2}} = \frac{k'_5}{n^{\frac{1}{2}}} \left(\frac{W}{E}\right)^{\frac{1}{2}} = 0.0219 \left(\frac{W}{E}\right)^{\frac{1}{2}} \quad (4)$$

which gives the diameter d, in inches, of a *solid* conductor. These diameters were in this case calculated for a solid conductor instead of a stranded one because we have at present available data as to the critical point in the atmospheric loss curve for solid conductors only, and while perhaps this critical point will come at a higher voltage in the case of the stranded conductor with its greater diameter, there are no definite data at present on the subject. On comparing the diameters of conductors given by Fig. 3 and the voltages to which they correspond with the values of diameter and critical voltage given by Professor Ryan* we see that the diameters of Fig. 3 are considerably above those of Prof. Ryan's paper. It appears, therefore, from the present knowledge available, that the limit of voltage will come through economic conditions, and not through limitations connected with atmospheric losses.

*See foot note, page 417.

In the determination of both x and E the quantity h has been employed. This quantity is a factor which, when multiplied into the cost of power at the low-tension bus-bars of the step-up transformers, will give the cost of power at the high-tension terminals of the transformers. That is to say, h takes account of all charges which should be made against this power, including interest and depreciation of the step-up station, transformers, etc., and labor for operating the station, also the loss in the transformers. Now, strictly, there should be substituted for h, the proper functions of the quantities on which it depends, but to do so would seriously complicate the equations and would be of little utility, since h can be approximated with sufficient accuracy in any particular case, and the manner in which it occurs in both x and E is such as to make the error in the quantities due to an error in h much smaller than the error in h itself. In the specific problem herein the value $c = 10.9$ is taken as being the lowest which will probably ever obtain, where large amounts of power are available within transmission distance of a desirable market. The value taken for h in the determination of E and x is $h = 1.1$, so that $hc = 12$.

The next step is the determination of the forms of the several functions indicated. In what follows the constants have been evaluated for the specific problem herein. The costs resulting from the use of these constants will be found to be, in general, considerably less than present commercial costs. The constants were purposely based on prices less than can be now obtained, in the endeavor to anticipate, somewhat, possible future prices.

From a careful consideration of transformer prices, it has been determined that, for transformers of 1500 kw. and over, the cost, installed, very closely follows the law,

$$f_1(E, W) = K_1'(E+K_1'')W^{3/4} = 13.(E+K_1'')W^{3/4},$$

$$\therefore p_1 f_1(E, W) = p_1 K_1'(E+K_1'')W^{3/4} = 1.625(E+K_1'')W^{3/4}$$

in which K_1' is a constant and K_1'' a "variable constant," a quantity which varies slowly with the output in accordance with the law,

$$K_1'' = k_1 + k_1'' W = 55 + 0.000227\,W$$

Theoretically the transformer cost would vary with the drop x_1, since the step-up transformers would have an output and voltage greater than the step-down transformers. Prac-

tically, however, step-up and step-down transformers are built so nearly in the same lines that the drop would make little difference. Such difference as would exist can be taken care of approximately by adjustment of the constants, which has been done.

While the apparatus for the control of the high-tension side of the transformers would theoretically vary with the voltage, such variation for 50 000 volts and over will be small, since in most modern plants the high-tension switching apparatus is simple; and higher voltages are likely to cause it to remain so. The lightning protection for the high-voltage lines might vary with the voltage, but it is probable that for high voltages there will soon be a reversion to much simpler and inexpensive apparatus than we use now, so that the variation, if any, due to higher voltages, will be negligible. The switchboard for the lower voltage side of the transformers will vary only with the output, since we assume the lower voltage to be the same in all cases, say 6000 volts or thereabouts. The apparatus for the control of transformers may, therefore, be considered as depending only upon output. Under this assumption a consideration of costs of transformer controlling apparatus and cables, shows that we may assume, with a close degree of accuracy, that

$$f_2\,(E, W) = K_2' + K_2'' W = 21\,000 + 0.9\ W$$

$$\therefore p_2 f_2\,(E, W) = p_2 K_2' + p_2 K_2'' W = 2625 + 0.1125\ W$$

The cost of buildings and the real estate for them will increase very slowly with the output. The variation of this item due to variation of output can be expressed closely enough by

$$f_3\,(W) = K_3' + K_3'' W^{\frac{1}{2}} = 125\,000 + 125\ W^{\frac{1}{2}}$$

$$\therefore p_3 f_3\,(W) = p_3 K_3' + p_3 K_3'' W^{\frac{1}{2}} = 9375 + 9.375\ W^{\frac{1}{2}}$$

The cost of an insulator will, theoretically, vary with the diameter of the conductor and the voltage. Practically, however, the diameter of the conductor will have nothing to do with the cost. A consideration of insulator prices shows that the cost of an insulator will vary as the sum of a small constant plus the product of a constant into the cube of the voltage. With high voltages the small constant is negligible, so that we may write

$$f_4\ (E, d, D) = K_4\ E^3\ (1+x_1)^3\ D = 0.000732\ (1.0645)^3 E^3 D = 0.000883\ E^3\ D.$$

$$\therefore p_4 f_4\,(E, d, D) = p_4 K_4 E^3\,(1+x_1)^3 D = 0.0000883\ E^3 D$$

The cost of the pole-line material and construction will depend somewhat upon the diameter of the conductors, since, as the diameter of the conductors increases, the wind and sleet stresses will increase. The increase of cost with increase in diameter of conductors will be slow. The law followed will be that of a constant plus a function of the diameter of conductors, since, no matter how small the diameter of conductor, there will be a certain cost representing the minimum sized pole which would be employed. We may, with a fair degree of accuracy, write

$$f_5\,(d, D) = (K_5' + K_5''\,d)\,D = f_5\,(E, W, x, D)$$

$$= K_5'\,D + K_5''\,k_5 \left(\frac{W\,D}{E^2\,x}\right)^{\frac{1}{2}} D$$

or, putting in the value of $x = n\dfrac{D}{E}$,

$$f_5\,(E, W, x, D) = K_5'\,D + \frac{K_5''\,k_5}{n^{\frac{1}{2}}}\left(\frac{W}{E}\right)^{\frac{1}{2}} D = 3000\,D + 37.2\left(\frac{W}{E}\right)^{\frac{1}{2}} D$$

$$\therefore\ p_5 f_5(E, W, x, D) = p_5 K_5'\,D + p_5\,\frac{K_5''\,k_5}{n^{\frac{1}{2}}}\left(\frac{W}{E}\right)^{\frac{1}{2}} D$$

$$= 375\,D + 4.65\left(\frac{W}{E}\right)^{\frac{1}{2}} D$$

which answers for a stranded conductor.

Cost of right of way will be directly proportional to distance, hence

$$f_6\,(D) = K_6\,D = 1000\,D$$

$$\therefore\ p_6 f_6\,(D) = p_6 K_6\,D = 50\,D$$

A consideration of synchronous motor prices shows that the cost of synchronous motors may be written,

$$f_7\,(W) = K_7' + K_7''\,W = 12\,000 + 5.4\,W$$

$$\therefore\ p_7 f_7\,(W) = p_7\,K_7' + p_7\,K_7''\,W = 1500 + 0.675\,W$$

The switchboards and cables for the motors will follow the same law as those for the transformers, hence

$$f_8\,(W) = K_8' + K_8''\,W = 8400 + 0.17\,W$$

$$\therefore\ p_8 f_8\,(W) = p_8 K_8' + p_8 K_8''\,W = 1050 + 0.02125\,W$$

From the well known relations between the cost of con-

ductors, and the voltage, distance, output, and drop, we may write

$$f_9\,(E, W, x, D) = K_9 \frac{W D^2}{E^2 x} = 0.346 \frac{W D^2}{E^2 x}$$

or, putting in the value of $x = n \frac{D}{E}$.

$$f_9\,(E, W, x, D) = K_9 \frac{W D}{E n} = \frac{K_9}{n} \frac{W D}{E} = 9.1 \frac{W D}{E}$$

$$\therefore p_9 f_9\,(E, W, x, D) = p_9 K_9 \frac{W D}{E\ n} = 0.455 \frac{W D}{E}$$

The cost of labor, for the operation of the step-up and step-down transformer stations, and for executive and clerical purposes, would probably not vary at all. We have, in each case, the same number of units to be looked after, and the size of these units would make little, if any, difference in the cost of attendance upon them. Similarly, the output will make little difference in executive and clerical costs. We should probably be justified in making $f_{10}\,(W)$ a constant. In order, however, to cover such small increase in labor and salaries as there might be with increase of output we will write

$$f_{10}\,(W) = K_{10}' + K_{10}'' W^{\frac{1}{2}} = 32\,000 + 26\,W^{\frac{1}{2}}$$

It is to be noted that the labor in connection with the line is taken care of in the depreciation and repair percentages applicable to the supporting structure and insulators respectively.

The efficiency of the whole system is $\frac{e_1}{1+x}$

Putting in the value of $x = n \frac{D}{E}$

$$e = \frac{e_1}{1 + n \frac{D}{E}} = \frac{0.925}{1 + 0.038 \frac{D}{E}}$$

$$\frac{W c}{e} = \frac{W \left(1 + n \frac{D}{E}\right) c}{e_1} = \frac{W c}{e_1} + \frac{n c}{e_1} \cdot \frac{WD}{E} = 11.78 W + 0.448 \frac{W D}{E}$$

The various functions above arrived at may now be utilized in obtaining N and M of equation (1), $p = \frac{N}{M}$.

Remembering that R is the sum of the products of the various functions by the corresponding percentages representing interest, depreciation, and repair; that $L = f_{10}\,(W)$, and representing the various resulting collections of constants as follows

$$
\begin{aligned}
a &= p_2 K_2'' + p_7 K_7'' + p_8 K_8'' &&= 0.788 \\
b &= K_{10}' + p_2 K_2' + p_3 K_3' + p_7 K_7' + p_8 K_8' &&= 46\,550 \\
m &= K_{10}'' + p_3 K_3'' &&= 35.38 \\
r &= p_5 K_5' + p_6 K_6 &&= 425
\end{aligned}
$$

then $N = W s - \dfrac{W c\,(1+x)}{e_1} - L - R$

$$= \left(s - \frac{c}{e_1} - a\right) W - \left(\frac{nc}{e_1} + \frac{p_9 K_9}{n}\right) \frac{W D}{E} - m W^{\frac{1}{2}} - p_1 K_1'(E + K_1'') W^{\frac{1}{2}}$$

$$- p_4 K_4 (1+x_1)^3 E^3 D - r D - \frac{p_5 K_5'' k_5}{n^{\frac{1}{2}}} \left(\frac{W}{E}\right)^{\frac{1}{2}} D - b.$$

Representing constants as follows

$$
\begin{aligned}
\alpha &= K_2'' + K_7'' + K_8'' &&= 6.47 \\
\beta &= K_2' + K_3' + K_7' + K_8' &&= 166\,400 \\
\gamma &= K_5' + K_6 &&= 4000
\end{aligned}
$$

$$M = \alpha W + \frac{K_9}{n} \frac{WD}{E} + K_3'' W^{\frac{1}{2}} + K_1'(E + K_1'') W^{\frac{1}{2}}$$

$$+ K_4 (1+x_1)^3 E^3 D + \gamma D + \frac{K_5'' k_5}{n^{\frac{1}{2}}} \left(\frac{W}{E}\right)^{\frac{1}{2}} D + \beta.$$

These values of N and M, if substituted in equation (1) will give, in its final form, the equation connecting distance, output, voltage, and profit, or, in connection with equation (3), for voltage, the relation between distance, output, and profit. Such substitution results in a cumbersome equation and will not be made here. If the various numerical values, already determined for the specific problem herein treated, be substituted in N and M, there results,

$$N = (s - 12.57) W - 0.903 \frac{W D}{E} - 35.38 W^{\frac{1}{2}} - 1.625 (E + K_1'') W^{\frac{1}{2}}$$

$$- 0.0000883 E^3 D - 425 D - 4.65 \left(\frac{W}{E}\right)^{\frac{1}{2}} D - 46\,550$$

$$M = 6.47 W + 9.1 \frac{W D}{E} + 125 W^{\frac{1}{2}} + 13 (E + K_1'') W^{\frac{1}{2}} + 0.000883 E^3 D$$

$$+ 4000 D + 37.2 \left(\frac{W}{E}\right)^{\frac{1}{2}} D + 166\,400.$$

Putting in this equation the various values of s and calculating the value of p for different outputs, W, and different distances D, the curves of Fig. 4 and Fig. 5 (and the other sets of similar curves for other prices of power) have been obtained. These curves show, for different values of W, the relation between p and D. Assuming that the minimum acceptable profit is 12 per cent. and taking from Fig. 4 and Fig. 5 and the other sets of similar curves (not included herein) the values of D and W corresponding to this percentage profit, there has been plotted the final curve, Fig. 6, which shows the relation between distance and output for the percentage profit assumed.

In considering these curves, the assumption made in connection with them should be carefully borne in mind. A small change in the purchase price or selling price of power will make a great difference in the result. Smaller amounts of power will in general be purchased at a higher price per kilowatt, but on the other hand they would probably be transmitted to points where the power would bring a higher price, since in general, the larger the market the cheaper can power be produced by steam; this fact compensates somewhat for the error in assuming the same purchase price for large and small amounts of power.

It would be interesting to let $s - c/e_1$ equal to zero and determine p which would then be the cost, including interest, of operating the plant. If curves showing the percentage of the investment for operation were thus determined, also the total cost of the plant, both for various outputs, the results would be valuable in preliminary estimates. The writer hopes to work up such data, later.

It will be noticed on referring to the curves that some of them reach to distances which cause the drop to exceed the value taken for the upper limit of drop in connection with insulator cost. The error due to 1 or 2% excess will not greatly affect the final result. It would have been somewhat better however to have chosen the limits of drop as 5% and 15% respectively instead of those taken.

Discussion on "The Maximum Distance to Which Power Can be Economically Transmitted."

President Lieb: It is gratifying to have had another pioneer paper from Mr. Mershon, presenting data for the solution of problems in the transmission of electrical energy, an important branch of electrical industry. Large parts of our western territory are vitally interested in the solution of these problems of transmission, notably the Pacific coast territory and vast tracts of land in need of irrigation.

The bringing of cheap industrial power into the mining centres is doing much toward lessening the cost of handling ores, making it possible to develop the poorer grades of ore. In the South also the economic conditions have been vastly improved by the utilization of the natural sources of power.

In Switzerland and Italy, for instance, it is hardly too much to say that the future prosperity of those countries is intimately bound up with the utilization of the vast sources of natural power, the "white coal" of the Alps.

While the speaker has no data at hand as to the extent to which the coal consumption is affected by the utilization of the water courses, the effect must be important, as industrial centres like the plain of Lombardy (Italy) are no longer operating their cotton mills and silk mills by steam power, but are now dependent upon electric power from transmission plants. When it is considered that almost all of the coal consumed in Italy is brought in bottoms from England, it is evident what an economic evolution such a change represents.

H. G. Stott: This paper is a most interesting one, not only to the engineer, but to the capitalist; for the modern trend of events shows that at no distant time the steam railroads in this country will in all probability be operated electrically. That in itself brings up the question of the maximum distance to which power can be economically transmitted; and the suggestion occurs at once whether we can transmit our power any more cheaply over wires than we can in the shape of coal in cars, and also which is the more reliable way of doing it. After all, every transmission scheme gets down to the question of reliability. An electrical transmission line, as we well know, is a sensitive piece of apparatus, subject to atmospheric disturbance, subject to the small boy with the kite, and with the piece of wire which he can throw over the line at any time. The freight-car is a pretty hardy piece of apparatus and not only hardy, but it has the possibility of a storage of power in the shape of coal at the point where the power is to be generated. The question of reliability is difficult to define, as to just what we want in the shape of reliability; power would not be considered reliable if the total interruptions per year exceed one hour. That criterion in some cases may be too exacting and in other cases not exacting enough. In large lighting plants, such as there are in New York, an interruption of one hour, unless taken care

of by storage-batteries, would be so serious a menace to the interests of the company and so annoying to the public that it would not be considered for a moment as permissible.

This paper deals with figures of 200 000 or 300 000 kw., and with distances of 550 miles. The transmission of power from Niagara Falls to New York would come well within the limits defined by the author, as the distance is approximately 450 miles and the amount of power used by the large plants in this city approximates 175 000 kilowatts.

The author makes the recommendation: " Frequency of transmission not less than 25 cycles nor more than 30 cycles as being the limiting frequencies," and in the paragraph immediately following is the statement: " Idle synchronous motors at step-down station to correct for power-factor, the average power-factor of the line being held as near unity as possible." By increasing the frequency we increase the capacity current of the line, and in that way can compensate for quite a large lagging power-factor. If there were not so many established plants using 25 cycles, the speaker thinks it would be profitable to discuss the question of using this frequency, whether 25 cycles is not too low. In the west, where 60 cycles is used almost exclusively, the power-factor is nearly always leading. That has another bearing on the cost of copper, and also eliminates the idle synchronous motors, which may be a source of much trouble in the case of disturbances, such as short circuits, on the line.

The principal criticism to be made is that the cost has been worked out without consideration of the load-factor, when it can not be expected that the load-factor will be greater than 50%, and this in turn affects the entire copper calculations. Examination of the mathematical analysis upon which the curves in this paper are based shows that load-factor has been entirely ignored and that the assumption has been made that power can be sold at a uniform price per kilowatt independent of the load-factor. Many attempts have been made to sell power upon this basis, but the speaker's experience is that they have ended in a mutual recognition by the producer and the consumer that it was not fair to the latter. $34.00 per kilowatt would mean that the cost per kilowatt-hour (on one-hour peak load lasting 309 days per annum) would be over 11 cents, or more than double the cost of steam power under the same load-factor. As a general proposition, it may be safely stated that no distant water power transmission plant can compete with a steam plant located near the point at which power is to be delivered, if the load-factor is less than 40% and coal less than $3.25 per ton.

In regard to the figure given of $10.90 per annum per kilowatt for power at the source of supply, there are few if any water-power plants developed for less than $100 per kilowatt, and some have gone as high as $190 per kilowatt, so that if we allow 12.5% for interest, depreciation, etc., as in the author's paper, the minimum cost per kilowatt would vary from $12.50 to $23.75.

Philip Torchio: Mr. Stott said he looked at this paper from the point of view of transmitting power from Niagara Falls to New York, or to similar large centres where there is a great market for power. This discussion will be somewhat from the same point of view, and not from the point of view of territories, such as exist in the West, where the cost of coal may be a great factor in the development of long-distance power transmission.

The general problem treated by the author involves the study of the two main factors which enter into the problem of power transmission, *i.e.*, the transmission pressure and the cross-section of the conductors. The elements which are affected by the pressure are the cost of transformers and insulators, which increase with the pressure, and the cost of line conductors and line losses, which decrease with the pressure. All the other elements are practically not influenced by the change in pressure. The author has treated the subject in detail, and has given a formula for the determination of the most economical transmission pressure. In this formula there enters the cost of line losses and interest and depreciation on conductors, both of which are dependent upon the most economical cross-section of conductors; therefore the dominating factor in a study of this character is the determination of the cross-section of conductors for the fixed conditions of each problem.

The author has adopted the Kelvin law for the determination of the cross-section of conductors, and he has obtained the results shown in Fig. 3, giving: " The diameter of the conductors for power purchased at $10.90 per kilowatt per annum."

The speaker has, during the last ten years, done considerable work on problems of transmission of power for a great variety of conditions; in all these studies he has made frequent use of the Kelvin law, which has been of great service to him. Its importance, however, is not generally recognized among engineers, perhaps for the reason of the great care which must be used in the selection of the factors entering into the formula, and also on account of the mistaken interpretation of the meaning of the formula which is often expected to give a general solution of any specific problem without regard to other requirements not taken into consideration by the Kelvin law. This law gives with accuracy the most economical cross-section of the conductors of a circuit in which we want a certain current to circulate. Other requirements, such as the safe carrying capacity of wires, the regulation, the brush discharges of high-pressure lines, etc., may substantially modify the conclusions arrived at from the consideration of the theoretical conditions of efficiency alone, and these modifying influences must be given due weight.

The speaker wishes to make a criticism in connection with the author's assumption of $10.90 per kilowatt per annum for the line losses, this being the same amount as paid for the main

bulk of current. The author, in this instance, failed to apply the very same principle which is one of the prominent features of the treatment of his paper, *i.e.*, "That the greater the output of a plant, the less is the cost per kilowatt of all the equipment." Now if there is a case where this general principle is unquestionably correct, it is the case of the increment cost of station equipment for amounts not exceeding say 5% or 10% of the total equipment; that is, if a plant of 100 000 kw. will cost, say $10 000 000 or $100 per kilowatt, we must certainly be able to increase the capacity of the apparatus say 10% at an increment cost considerably less than the average of $100 per kilowatt. The fact that in the paper the power is assumed to be purchased at a fixed rate per kilowatt will not alter conditions, as the saving derived from this increment cost of generating equipment will be felt either directly or indirectly by the transmitting company, either by lower fixed charges for the operation of the generating plant, or lower price of power charged by the generating company. If the transmitting company owns and operates the generating plant as well, nobody will question the above reasoning. The speaker does not see any reason why the same should not hold for the two enterprises operated independently; at least in this theoretical discussion such assumption should be made. If this had been done, per haps the increment cost of power for line losses and other losses would have been $5.45 instead of $10.90 per kilowatt, while the cost of power delivered would have been slightly increased by the necessary amount so that the average of all power would still amount to $10.90 per kilowatt as before. This change in cost of power for line losses would have considerably changed the final results. The cross-sections of conductors given in Table 3, all of which are based on approximately 2500 circular mils per ampere, would have been changed to the basis of 1750 circular mils per ampere, thereby reducing the total cost of conductors about 30%. The economical voltages of Fig. 1 would have been somewhat changed, while the curves of economical energy drop of Fig. 2 would have been raised about 42%. By referring to Fig. 2 we see that such increase in energy drop would be permissible for all cases up to about 200 miles; this at least for the curves of larger outputs. For longer distances we should meet serious objections, especially for the curves of smaller outputs. These limitations are dependent upon the character of apparatus supplied at the receiving end of the line. In general the presence of different types of apparatus will limit the maximum energy drop to the following amounts:

Synchronous converters, about	10%
Synchronous motors, about	15%
Induction motors, about	20%

This brings into play a new factor which is not taken into account by the formulas. Any conclusions that might be derived from the analytical treatment must be ultimately revised

to meet the above requirements of maximum energy drop. In the case of very long transmission lines, necessarily involving large amounts of power, synchronous converters will usually be found present under existing American conditions. This fact not only would prevent us from reducing the cross-section of conductors as given in the author's paper, but it would also necessitate a further increase of cross-section for reducing the maximum energy drop, and therefore cause a reduction in the limiting distance of the present outlook for power transmission as given in the concluding paragraphs of the paper, where the limiting distance is given as approximately 550 miles.

In making further criticism, the speaker has in mind that this paper is of a pioneer character, and therefore should only be discussed upon broad lines. We must assume ideal conditions and we must even allow something that may appear problematical at the present time. The author has correlated a great amount of knowledge and information in the ten formulas giving the elements of cost of the transmitting systems. The speaker would like to question some of the items and assumptions, for instance; the use of a single pole line and single route; the arrangement and number of transformers for the different outputs; the 5% rate of interest for capital invested in an enterprise of this character; and other items. But he believes it would not be fair nor profitable to open a discussion upon these points. He believes, however, that exception could be taken to some of the fundamental assumptions.

On page 411, first line, the author says; "It is certain that with the course of time the value of power will increase." If this statement is applied to a definite period of time covering say 25 or even 50 years from now, we are entitled to question its plausibility. The cost of power derived from coal will, for centuries to come, apparently govern the cost of power throughout the greater part of the North American continent. If other sources of power be used, they must compete favorably with the power from coal. The coal deposits of the United States and Canada are so large that coal-trade experts have not yet made an inventory of the probable supply. There are now immense coal fields entirely untouched. At present the rate of consumption of coal in the United States is exactly 1 000 000 tons a day. Of this amount probably less than 5% is consumed for generating electricity for all purposes. From the U. S. Census Reports for the year ending June 30, 1902, we gather the following approximate total current output and total station

	Dynamo Capacity Installed horse power	Total Yearly Output Kilowatt-hours	Estimated Load-Factor
Electric Light Station..	1 624 980	2 453 502 652	23%
Electric Railway Station	1 159 002	2 261 484 397	30%
Total...........	2 783 982 2 075 000 kw.	4 714 987 049	26%

capacity of all electric light and electric railway stations. (The load-factors shown are obtained on the assumption that the maximum load was equal to the dynamo capacity installed.)

If all electric current had been generated by steam, the total coal consumption would have been less than 20 000 000 tons at the most (on a consumption of five pounds per kilowatt hour the total would have been less than 12 000 000 tons). This amount is insignificant compared with the 1 000 000 daily consumption for all purposes. Now if we consider the great available supply of coal and the extent of its industrial and domestic uses, and the fact that cheap coal will be one of the fundamental factors enhancing the industrial supremacy of this country, it is hardly probable that the cost of coal will be abnormally raised from the present level, except for the gradual increase of cost of mining and the increase in wages that might follow a general raising of prices for all labor and supplies and an abnormal rate of increase of production of gold tending to depreciate the money value. On the other hand, while we may not expect to obtain coal at a lower price than at present, and may probably have to pay more for it in future, it is also quite probable that though the new rotary steam-engine, *per se*, will not revolutionize the cost of power production, it will eventually lead us to the development of the rotary-gas-engine, which will make it feasible to realize enormous savings in the production of power. Therefore, while we may have momentary fluctuations of values of power, we are quite justified in expecting still further reductions for many years, before the curve of values of power shall have reversed its present lowering course and begun to climb.

This preamble was necessary to bring on the proper plane the discussion of the price of power assumed by the author. He puts this value at $34.00 per kilowatt per year. Let us assume that the equivalent of the total loads of all United States electric light and railway stations operated during the year ending June 1902 were grouped within a radius of 10 or 15 miles of the ends of four 518 750-kw. transmitting lines 500 miles long. On the basis of $34.00 per kilowatt per year the total power cost would have been 2 075 000 × 34 = $70 550 000. This does not include the cost of distributing the power to the several consumers within the 10- or 15-mile radius.

Furthermore, the great bulk of the 25-cycle current would have to be converted to some other form before being used for the respective requirements, with attendant losses. Therefore the above cost would have to be increased by 10 to 20% for losses in transmission to and conversion of the 25-cycle current at the customers' sub-stations, plus interest, depreciation, repairs and taxes on lines, cables and subways, sub-station real estate and buildings, and sub-station transforming and converting apparatus, plus the labor and operating charges for the operation of the sub-stations. The aggregate of these items would

probably amount to about \$22 500 000. For the sake of simplicity let us assume that this amount would offset the capital charges on real estate and buildings plus the labor production charges for the present steam generating stations. Then we should have left for direct comparison on one side the total cost of water power of \$70 550 000 and on the other side the cost of fuel plus the interest and depreciation on the generating equipment, excluding real estate and buildings. It is estimated from the figures given in the Census Report that the electric stations paid for all kinds of fuel to generate their total output about 0.45 cents per kilowatt-hour, or \$21 200 000 total.

The first cost of steam generating equipment in large stations, exclusive of real estate and buildings, making allowance for future reduction of cost of apparatus, can be safely estimated not to exceed \$100.00 per kilowatt. The total cost of generating equipment for 2 075 000 kw. would amount to \$207 500 000, and at the rate of 12.5% interest and depreciation, the capital charges per year would be \$25 937 500. This added to the cost of fuel would make the total \$47 137 500, to be compared with the \$70 550 000 cost of water power. We therefore see that the \$34.00 per kilowatt per year is excessive, and that on the basis of the operation of all the electric light and railway stations of the United States for the year ending June 30, 1902, the price should have been reduced to $\frac{47\,137\,500}{70\,550\,000}\times 34 = \$22.72$. An approximately identical conclusion can be arrived at by figuring the different elements of power cost from an ideal steam plant and comparing them with the corresponding costs of water-power; but it is not necessary to go into further discussion on this point. Therefore the price of \$22.72 per kilowatt per annum for water-power transmitted 500 miles under the conditions given in the author's paper, the speaker considers an outside limit, as it would not give any financial inducement to the consumers to sacrifice the safety and reliability of control of the local steam plants in favor of long-distance transmission power with the attendant dangers of breakdowns met in the operation of such an extensive system of water-power generation and transmission —all depending upon the safety of a single pole-line exposed to all the dangers of weather, defective materials, or malicious acts of men. It is only necessary to mention these drawbacks, as persons familiar with the requirements of continuity of service in large systems will at once draw the proper conclusions.

If water power will ever be transmitted to large markets like New York, Chicago, etc., it will be necessary to keep at these centres an equivalent reserve steam generating capacity; first, for tying over shutdowns of the transmission power; and secondly, for taking care of a great proportion of the power required during the periods of heavy loads, thereby utilizing the water power for the 24 hours of each day with a load-factor of say 60% or over, and operating the steam plants at a very low load-

factor so as to save fuel. On account of the uncertain duration of shutdowns, storage-batteries could only be used to take care of the loads during the period of starting up the steam-generating plants.

P. G. Gossler: Mr. Torchio says that he considers the author's statement of power sold at $34.00 per kilowatt to be the outside limit; that he considers it necessary to sell power at about $22.00 per kilowatt or $17.00 per horse power to compete with the cost of steam. The speaker understands the author's price, $34.00 is for the sale of the power at the time of peak load. If Mr. Torchio's $22.00 per kilowatt is based on the average load-factor of 23%, as he gives it, and the power can be sold at about $97.00 per horse power, then the author is well within the limit. If the $17.00 per horse power is for the maximum the speaker fears that most of the water power companies would be forced into the hands of receivers if that price were maintained.

Philip Torchio: $22.72 was per kilowatt maximum and not per kilowatt average. That was arrived at by taking the dynamo capacity installed of all the lighting companies and railway companies of the United States to be equivalent to their maximum load.

P. G. Gossler: It is hardly fair to let the impression go out that the average price of power per horse power is $17.00. The speaker does not think it is based upon facts, the facts upon which commercial business is usually conducted.

Philip Torchio: The $17.00 per horse power referred to in the speaker's remarks is not the retail selling price of power delivered to the consumer. It only includes the interest and depreciation of machinery, exclusive of real estate and buildings, plus the cost of coal, which items the speaker assumed to represent the wholesale value of water power delivered at the purchaser's switchboard under the specific conditions of load factor, etc., given in those remarks. Nothing else is included in that figure. On the other hand, the selling price charged by a company retailing power will be dependent upon the use and the load-factor; and furthermore, in that price must be included a number of other items, as the production labor cost, the interest and depreciation, and taxes on real estate and buildings, and also on the distributing lines and subways; also the cost of distribution labor and repairs, and if it is a lighting company, the cost of supplies and maintenance of the customers' lamps; also it will include all the items of general expense that make up the total cost of power delivered to the customer, including management, accounting, canvassing, insurance, legal, medical, and damages, etc., and finally the charge for profit to the company.

J. E. Wallace: Assuming that the mathematics underlying the curves given in Fig. 1 are correct, the speaker considers that a grave error in engineering judgment would be committed by

following them. To substantiate this statement, the speaker calls attention to a short press article written by him and published in a recent issue of the *Electrical World and Engineer.**

One of the curves used to illustrate this article shows how the cost per kilowatt of energy delivered decreases with increased pressure. Beyond a pressure of 60 000 volts, in this particular case, the drop in the curve is hardly worth considering. The increased cost of insulators and transformers, due to increased pressure, is neglected in the curve; if included, it would ultimately overcome the slight drop beyond 60,000 volts and the curve would take an upward turn, locating economic pressure. Considering a factor for more reliable operation at lower pressures, the slight advantages gained in costs of delivered energy, as economic pressure is approached, do not warrant the very considerable increase in pressure.

With increase of output the cost of transformers is decreased to some extent, and the pole construction item decreases by a ratio that practically varies inversely as the output; possible failure of a line, however, should impose a limitation which would not allow the process to go on to an almost indefinite point. With a given increase in output the effect is to make economic pressure higher, as found by the author. Engineers agree that practical conditions govern theory, and it is held by the speaker that in deciding on the transmitting pressure to be employed, the advantages to be gained by increased pressure should again be compared with the factor for more reliable operation at a lower pressure, which factor naturally would increase with increased load for which a given pole line is responsible.

The conditions on which the curves in Figs. 4 and 5 of the author's paper are based are somewhat special; the total investment does not include the principal item of cost in a transmission scheme—the cost of the generating plant. Large profits could easily be figured under such conditions. The market price of delivered energy, and load-factor on both generating plant and transmission line, af well as cost of energy delivered to the line, are factors that have an influence on profitable efficiencies.

At the outset this paper claimed to be in the nature of a forecast of what might be done in the future. The author has said that a 12% profit is necessary to guarantee the bonds; it is presumed that the full issue of the common stock will be represented in the construction costs. The author does not give the proportion of stock to bonds, so we shall assume the usual proportion, 50% of each. Five per cent. for interest, and seven and a half per cent. for maintenance and depreciation are the figures given; they will be allowed for the generating plant. This means that one-half of the construction costs must earn 12.5% and the other half 19.5%, or an average of 16% on the whole; $10.90 is given as the amount that the generating plant will receive per kilowatt. Assumed that it does not cost more

**Electrical World and Engineer*, Nov. 5, 1904.

than 90c. per kilowatt for attendance; we then have $10.00 repsenting 16% of the construction costs per kilowatt of the plant. $62.50 is an exceedingly small figure with which to pay for water rights, hydraulic developments, water-wheels, generating apparatus and the various other accessories necessary to a generating plant.

Watt-losses are considered in terms of a delivered kilowatt. It is apparent that if a line has 90% efficiency, there is a loss of 10% of the generated energy. Considering line resistance, it is also apparent that the annual conductor charges vary inversely as the per cent. loss; therefore the conductor charges are represented as a constant divided by the per cent. loss, thus $\frac{\text{constant}}{E^2\,(1-f)}$ where f equals line efficiency. At the other end of the line the relation of conductor charges per generated kilowatt to conductor charges per delivered kilowatt, is the same expression divided by the efficiency of the line; this gives $\frac{\text{constant}}{E^2\,(1-f)f}$ In other words, the conductor charges in terms of a delivered kilowatt vary inversely as the per cent. loss multiplied by the efficiency of the line. If one considers conductor losses in the per cent. of a delivered kilowatt, and neglects to consider that the delivered kilowatt is a function of the efficiency of the line, one is led into error. This error evidently led the author to Kelvin's law. With all due reverence to Lord Kelvin, the speaker contends that Kelvin's law does not deliver the cheapest kilowatt. At any practical pressure the error in Kelvin's law is, in the matter of a delivered kilowatt, rather inconsiderable; but the error multiplies and soon becomes formidable when it is carried into efficiencies for percentage returns. Anyone who cares to look up the subject will discover the truth of this statement.

M. H. GERRY, JR: A mathematical analysis of a subject of this kind has always seemed to the speaker to be of doubtful utility, not necessarily because of any defect in the process of reasoning, but because there are so many variables entering into the expressions. In order to apply such an analysis where the conditions are so far in advance of current practice, it is necessary to make arbitrary assumptions based on the judgment of the individual engineer; and the final deductions are so much affected by the assumed values as to render them little more than an individual opinion instead of being facts founded on mathematical reasoning.

Taking the author's expressions and modifying his assumptions, it can be shown that the economical limit of distance of powér transmission in a given case may be either 100 miles or 1000 miles, and this being the case the mathematical development is of little value from an engineering standpoint as a means of predicting ultimate commercial results. This paper is, however, of considerable interest from its theoretical side. The mathematical expressions are in good form, and will prove of value in the future when more is known of the physical and

commercial conditions surrounding the transmission of energy at the excessively high pressures and great distances referred to. At the present time the information before us regarding pressures above 100 000 volts is so limited as to make substitutions in the various mathematical expressions of very doubtful value; it is certainly not wise to attempt to show in this way the limitations of distance for future electrical transmissions. Such statements are misleading and should not appear unchallenged in the PROCEEDINGS of the INSTITUTE,

A. E. KENNELLY: We are indebted to the author of this paper for a careful analysis of the problem of the commercial limits of electric power transmission under clearly specified conditions. There is no pretence that these conditions are immediately available for general estimates. The pressures are much in excess of those in commercial use to-day, and the power assumed is also much greater than the power ordinarily transmitted. Nevertheless, the solution of the economic problem for definitely assumed pressures and kilowatts is perfectly proper matter for discussion, as an abstract proposition, quite independently of the question as to when such pressures and powers will be practically available in the future.

The history of electric power transmission in the past shows that it is unsafe to prophecy the commercial limiting distance of transmission. In the early days of the development of the incandescent lamp it was demonstrated mathematically that it would be commercially impracticable to transmit electric power to such lamps more than a few hundred feet. The proposition was valid at the time, but only for the conditions then existing. The three-wire system and the 100-volt lamp upset both the assumptions and the conclusions. The practical men carried power to lamps distant several thousand feet from the generator. Then the transformer became known and it was demonstrated that it would be commercially impossible to transmit power more than a few miles. But improvements in construction invalidated the assumptions of this proposition also, and the practical men have now succeeded in carrying power commercially to a distance of 230 miles in California at a pressure of about 60 kilovolts. The conclusion of the author's paper is that under the conditions he has assumed, power may be carried about 500 miles and pay a profit, if the block of power is large, say 200 megawatts. This conclusion is interesting, because it would place both New York and Chicago within the sphere of influence of Niagara Falls. But a yet more important deduction in the paper is that when power is transmitted in such bulk as is considered in the paper, it pays to use copper wires so large that even at 170 kilovolts between them, there will be no dissipation of power by brush discharge. In other words, aluminum wires will not be rendered necessary for long distance transmission of large blocks of power, since the copper wires would have sufficient diameter to keep the electric gradient in the air down to the safe working value and below the smashing point.

Curiously enough, the distance the author arrives at (500 to 600 miles) is about the same as that to which telegraphers generally carry their small amounts of power over wires for transmitting messages. For distances exceeding 500 or 600 miles they usually insert a repeater.

CHARLES F. SCOTT: The author's paper is the outcome of several years of study of the problem of long-distance transmission in which he has dealt with it in various ways. Several years ago he did some excellent work in determining experimentally in Colorado, on a circuit of the Telluride Power Transmission Company, the loss through the air between wires at low pressure. The curve representing this loss shows that it is extremely small under the conditions which the author employed until approximately 60 000 volts was reached, when the curve took an upward turn and a slight increase in pressure caused a very great increase in loss. It was evident that a pressure much above 60 000 would cause a loss so great as to be prohibitive. The wires which the author used were small in diameter. The critical point at which loss begins occurs at a higher pressure when the wires are of greater diameter. This matter was admirably set forth in Professor Ryan's paper before the INSTITUTE about a year ago.

The author now considers the general problem of power transmission from the commercial rather than from the scientific side, and one may readily imagine that the problem was one which grew larger and larger as he worked upon it, for the paper shows the result of painstaking labor. Nearly all of the papers which are written upon transmission deal with certain specific elements and do not take up the subject in a broad way. At the International Electrical Congress, for example, there were many papers in the Transmission Section, but these papers dealt with specific or with local matters such as details of construction, types of insulators, characteristics of conductors, methods of operation and the like. There was no broad general paper, except one which was read by title. That paper was prepared by an official representative to the Congress from the INSTITUTE and it is the paper which has been presented to us this evening.

Some objection has been raised to the use of specific figures by the author. The particular value of the paper is found in its treatment of a general engineering problem and in the bringing together and showing the relation between the various elements which enter into commercial power transmission, The paper, however, would lose much in interest and in value if it presented simply the formula showing the relation between various variables and constants without assigning definite commercial values. These values are of course liable to change, but the whole matter assumes a much more definite, and satisfactory condition, if in addition to the abstract relationships there are given also the concrete values which result when certain reasonable values are given to the different quantities

involved. It is, for example, a satisfaction to know that under conditions which are fairly commercial the distance from Niagara Falls to New York City is not beyond the limits of commercial possibility.

This paper deals with something outside of the range of electrical operation with which we are familiar. If we were to refer to the wire tables of 15 years ago we would find that the units then used were 16 c-p. lights and that the distance ran up into a few hundred or a few thousand feet. Electrical work at the present time is on a much larger scale, and the present paper goes far beyond our present needs. The curves give little attention to units less than 50 000 kw., which is about the output of the largest stations which are now in operation. Many of the conditions set forth in the present paper do not apply to less than 200 000 h.p., which is probably about the amount of electrical power used in New York City. The field of power transmission which is considered in the present paper is therefore one which does lie in the present, but which we may encounter a decade hence. It gives us a vision of the electrical future.

An interesting point may be noted relatively to the percentage of loss in transmission. Most of us would probably estimate the desirable loss in transmission over considerable distances at 10 or 15%. The curves in the present paper show that for 100 miles the economic drop does not exceed more than about 5% and that for less than 100 miles the loss would be considerably smaller. Up to even 200 miles the losses on the curves representing all the conditions considered do not exceed nine per cent.

High pressures have usually involved the idea of a small wire, and in some of the earlier transmission systems the limit of the size of wire was fixed not by its conductivity but by its mechanical strength—electrically the conductor could be made smaller than was made necessary by the requirements of mechanical strength. The present paper shows that we have gotten into a new order of things in power transmission on a large scale, as the size of wire for economic transmission for large power at high pressure is so great as to bring about the surprising result that the atmospheric losses which have been assumed to be the determining element in high pressure transmission no longer determine the maximum pressure; the size of wire required at a given pressure to insure economic transmission is so great that the atmospheric losses are avoided.

C. L. de Muralt: In the author's paper the fact stands out prominently that it is in all probability the economical side of the problem and not the technical side, which determines the distance to which energy may be transmitted electrically. Let us therefore look more closely at the economical variable of his equations.

The author has taken the price of $34.00 per kilowatt per year

as a selling price for the transmitted energy. In Switzerland, which may be called the power transmission country par excellence, electric energy is sold in most cases at about $20 per horse power per year, or approximately $30 per kilowatt per year. But you know that coal is very high in Switzerland—it is here about $2 per ton, and there $6 or $8—if therefore in Switzerland competition of coal has to be met by selling the kilowatt per year at $30, it would seem difficult to obtain $34 in this part of the world where fuel is so much cheaper. The author's curves, notably Fig. 5, show very nicely how the maximum distance, over which energy can be economically transmitted, may be increased by increasing either the amount of energy transmitted or the pressure of transmission, or both. But if in his curves the selling price is reduced to what it will have to be to compete with coal, then the distance of transmission will in a great many cases be materially decreased, no matter how large the amount of transmitted energy or how high the pressure of transmission. If, for example, conditions are taken as they are now around New York it would seem doubtful if this distance would be more than half of that shown in Figs. 4 and 5. This is the point the speaker wishes to bring out.

RALPH D. MERSHON: The difference of opinion which has developed here to-night is no greater than was to be expected. Probably there never were two engineers who estimated in exactly the same way on everything, or whose estimates on a proposition, if examined in detail, would agree exactly; one man would be higher on one item and lower on another, although the total estimates made by them might agree very closely. Moreover, in making estimates, it is not an uncommon experience to have the figures on some details higher and on others lower than the figures actually obtained in the construction for which the estimate was made; the result being an equalization of the positive and negative errors, and the total estimate comparing very closely with the cost of the completed work. Such a condition of affairs does not argue any lack of skill in estimating, especially on work along new and untried lines, and the engineer is legitimately entitled to such equalizing chances as those mentioned.

This paper, in so far as the numerical values are concerned at least, represents simply a piece of estimating. In considering the numerical values of the paper, therefore, too much stress should not be laid upon details. The principal consideration should be given to the work as a whole.

On the different items of the paper there will be differences of opinion among engineers, both as to assumptions and numerical values; but the average opinion, if one could get at it, would probably come very close to the figures given in the paper.

Suppose, however, that there were errors in the paper sufficiently great to cause an error in the limiting distances de-

duced, as great as 20%. Even with that error the value of the paper, as giving a general view of the subject, would not be diminished to any considerable extent.

As Mr. Scott has said, such a paper as this is more interesting with some definite figures than if it gave simply an analysis, and hence the numerical values were introduced. No exceptions worthy of notice have been taken to the method of analysis employed.

The two extremes that Mr. Gerry mentioned, namely, 200 miles and 2000 miles, between which the limiting distance of transmission might fall, are pretty far apart. Probably the idea that Mr. Gerry means to convey is that the conditions under which a transmission might be undertaken might vary so widely in different locations, especially as to the cost and selling price of power, as to render very uncertain the limiting distance when treated as a general question. But, as the paper shows, the limiting distance of transmission will, among other things, depend very greatly upon the total output of the plant, the distance being greater for greater outputs. Now the assumption of a large market and a large source of power to supply it narrows the location of the transmission very considerably, and this in turn fixes the values of cost between narrower limits than those which Mr. Gerry probably has in mind.

In this paper there is done, in a general way, just what Mr. Gerry does when he estimates on a particular plant. He takes a specific case and makes an estimate. The speaker has tried to make the estimate in a general way; that is, instead of considering various plants separately and undertaking to work out something for each one, by means of formulas the problem is put in such shape that by working out a comparatively few values, results can be obtained for plants whose outputs cover a considerable range, thus enabling one to get a much clearer idea of the trend of results as the various quantities are varied.

Mr. Stott brought out a number of interesting points, one of them the question of the sale of power on a flat rate; another, the consideration of the load-factor. But in this problem there is no need to consider the load-factor, or any charge except the flat rate, for the reason that no matter what the load-factor or what the price we may sell the power for, there is always a certain peak and certain income; divide the income by the peak, and you have a certain flat rate. That is the figure which must be considered in a problem of this kind, for the reason that in the water power plant—which we are necessarily considering—there is practically no variable factor. In the steam plant there is a variable factor, the cost of fuel. In a water-power plant it costs practically the same per kilowatt whether you deliver one-quarter of the output or the whole. It makes little difference what proportion of the

full capacity is carried; some, perhaps, but not enough worth considering in a paper of this sort. Mr. Stott also spoke of the question of carrying the peak load. The problem does not necessarily assume that the peak load will be carried. Take the case of bringing power to New York City. There are pretty large steam plants here. It would be cheaper, in general practice, to carry the peaks on these steam plants and get a more uniform load on the water-power plant, which would enable the purchaser to pay a higher price per kilowatt per year than otherwise.

As to the cost of the generating plant, as represented in he price assumed in the figure for cost of power, it is low; but not impossibly low. There are some water powers throughout the country where the cost of the plant, and therefore of the power, is very low, because of advantageous physical conditions. But aside from that, supposing the development to be similar to that at Niagara Falls; in the case of blocks of power as large as those considered and as more power plants are installed, and more skill and experience is brought to bear upon them, the cost of power from such developments will be very considerably diminished from what it is now. Mr. Stott brought up the question of higher frequency in order to get better power-factors, but there are a good many arguments against that. If the load were very well distributed, along the transmission line, higher frequency is a matter which might be worthy of consideration; but generally the load is bunched at the end of the line, and in such cases the lower frequency would undoubtedly be preferable.

Mr. Torchio's contribution is a very interesting one, but there is so much in it that one can not follow it closely enough, hearing it for the first time, to reply to it. After reading it more carefully, the speaker may perhaps reply with a written communication. The cost Mr. Torchio has taken for power is remarkably low, certainly lower than any that the speaker has investigated. The criticism which Mr. Torchio made in regard to assuming one cost for the power produced is, from some standpoints, a legitimate one, although if he will turn to page 432, in the middle of the page he will see a paragraph which deals with this question and calls attention to a compensating factor. The reason for taking one cost of power was simplicity. The aim was to determine the maximum distance to which power could be transmitted, and with that in view perhaps the curves of small output should have been omitted. But they are of interest in connection with the compensating advantage, mentioned on page 781, which will have some effect. The power cost assumed, therefore, is that which would best apply to very large outputs, to those large outputs determining the maximum distance of transmission. As Mr. Torchio can see, it would complicate the equations still more to introduce a variable factor in the cost of power.

Strictly, the proper method of applying the equations is to start with a certain cost of power, and a certain sale price of power, and determine how far it could be transmitted. In that case there might be a different cost of power and different selling price for each size of plant.

Replying to Mr. de Muralt, in regard to power prices in Switzerland: he should bear in mind that as a general thing apparatus, labor, and money are cheaper in Switzerland than in this country.

In regard to the question of bonds mentioned, 5% interest was assumed on the actual investment, and 12% of the investment taken as profit. That does not mean necessarily that the bonds should be rated at 5%, or issued on the basis of returning 5%. It means that the return has been divided into two amounts, one 5% and the other 12%. The total return is 17%, and you can divide it between dividends and bonds as you please.

As regards Mr. Wallace, his quarrel seems to be with Lord Kelvin, in which case no reply is necessary. Mr. Torchio will find, if he carefully examines the equations, that the Kelvin law has been given full weight and has been modified only by those elements of cost of transmission affected by change of pressure.

Ralph D. Mershon (by letter, after adjournment): Mr. Torchio has criticised the assumption of the same cost of power for plants of all capacities; to this the writer has already replied. But in addition, Mr. Torchio discusses the question of squeezing a little more power out of a generating plant to make up for the line loss, and the possibility of obtaining this increment of power at a lower cost than the bulk of the power produced by the station. The writer cannot agree with his argument, even if it be made on the assumption that the same company owns both the transmitting plant and the generating plant. In the case of a generating plant of a given capacity, the cost of power produced by that plant would be computed; and for any increased output, no matter how great, there would be computed the corresponding cost in accordance with the law governing the variation of such cost with output. Why the law of variation should be any different for large or small increments is not quite clear to the writer. The fallacy of Mr. Torchio's argument can be shown by carrying it a little further. After having obtained 10% more by the method he advocates, why not obtain another 10% by the same squeezing process, and so on to any amount of power required?

Touching the drop limitations mentioned by Mr. Torchio as imposed by the various kinds of apparatus, the writer believes that the limitations in this direction, due to synchronous apparatus, will be removed in the near future. The assumption that large numbers of synchronous converters must of necessity be used is not in any case in accord with the writer's ideas on

the subject. He believes the time will come when there will be little use for synchronous converters, alternating currents being used for almost all industrial purposes.

There is a point in regard to the transmission line which Mr. Torchio has overlooked; namely, that the paper assumes three transmission lines. Perhaps it is not so clearly stated as should be that these three are distinct and separate and on separate structures, but such is the assumption.

The writer has not at hand the data for entering into a discussion on the probability of an increase of fuel costs. The statement that the value of power will increase was based partly, but not wholly, upon this consideration. The writer believes it is generally deduced by statisticians that it will not be very long before the price of fuel will increase to a point where it will be seriously felt; this of course being due, not only to the diminution of the source of supply, but also to increase of population and its increased demands for fuel and the materials whose production involves its consumption. But there is another reason why the value of *electric* power will increase, and that is that as the delivery of such power becomes more and more reliable, the price will be regulated, not, as now, by the consideration of supplying power to a customer who has a duplicate steam plant, the fixed charges on which must be carried, but on the basis of supplying a customer who has no steam plant except such as is necessary for carrying his peak. Carrying the peak by steam will make it possible for the purchaser to pay a higher price for water-power than he otherwise would, and yet result in a lower total cost of power to him than though he carried the whole load by steam. This question of a combination plant would, if considered by Mr. Torchio, compel him very materially to modify the figures of his general and very interesting discussion as to the selling price of power.

The writer questions very strongly the statement made by Mr. Torchio, that it is necessary to carry "equivalent reserve steam generating capacity" in the case of transmitting power to Chicago or New York. A certain amount of reserve may have to be carried to provide for extreme emergencies, but the writer thinks that in time the amount of such reserve will be more and more reduced. This has been the experience with transmission on a smaller scale, and the writer sees no reason why, as the art advances, it should not be the case even in a greater degree with larger enterprises.

Referring to Mr. Wallace's statement, as based upon some figures he has made for a specific case, if he had selected a plant of an output or distance of transmission differing from that assumed by him and had applied the same criterion as he has applied to the question of economical pressure, he would have arrived at a different pressure for each output and distance; in other words, he would have obtained results resembling those in the writer's paper.

Regarding the question of the figure assumed for the cost of power ($10.90 per kilowatt at the step-up transformers), the assumption made is a possible one, commercially. The best proof of this statement is that power has been and is being produced for less than the price named. Some of the members present at the meeting at which the writer's paper was discussed could, if they had felt at liberty to do so, told of power being produced at a considerably less figure. It is well known that, in a city not very far from New York, power is sold at $15 per horse power, this price to fall to $14 when the total load shall exceed 10 000 h.p. This power is transmitted from a water-power 85 miles away, and is sold at a profit. One can, if he chooses, figure back and determine roughly what the power must cost at the terminals of the step-up transformers.

If any one desires to purchase power at the point of generation for $10.90 per kilowatt per annum, he can perhaps be accommodated up to 200 000 h.p.

In view of the discussion which has taken place in regard to the selling price of delivered power, the writer purposes to plot another set of curves which will apply to a lower selling price than that assumed in the paper, and shall include them in the paper with the curves applying to the selling price of $34 per kilowatt already assumed.

In the numerical calculations of the paper, which are long and somewhat involved, there crept in an error in the cost of synchronous motors, although extreme pains were taken to have all figures carefully checked by two or more persons. In the final printing of this paper in the TRANSACTIONS of the INSTITUTE, this error will be corrected. The correction will modify the distance curves, Figs. 4 and 5 already given, by increasing the profitable distance of transmission under the conditions assumed; it will not change the other curves.

Discussion on "The Maximum Distance to Which Power Can Be Economically Transmitted," at Pittsburg, Pa., January 9, 1905.

S. M. Kintner: The author has given us a paper that is exceedingly broad in its scope, so broad that few, if any, are in a position to check it. The author has probably got more good out of the paper than any one else, in the very thorough investigation that was necessary for its preparation. In saying this it is not intended to detract from its value, for it is the belief of the speaker that this paper will prove of great value to more of us when we learn more about the constants involved and when higher pressures and larger powers are used commercially. The author has committed himself to but few engineering points, but some of these involve quantities of such magnitude that one is astonished in considering them, yet that is no reason for condemning the paper.

Such high pressures, which are now looked upon as abnormal commercially, and such large sized plants, also far beyond anything known in present practice, may bring about changes in design that will readily take care of present anticipated troubles. There is always great uncertainty in drawing conclusions from curves extended far beyond the observed values, for the curve is just as liable to go down as up. The author's range of constants will provide considerable latitude.

Though there may be many points of detail upon which one may not agree with the author, yet it is the opinion of the speaker that a thorough study of the paper will repay one and give a broad view of all the most important elements considered, a view so broad that corrections can readily be made from time to time, as experience dictates.

P. M. Lincoln: It seems to the speaker that the author's deductions are open to considerable criticism. He has developed a number of laws for costs of the various elements which go to make up a transmission line, and these laws are expected to hold true for an amount of power up to at least 500 000 kw. and pressures up to at least 200 000 volts. These limits are far beyond anything which is in existence to-day. The speaker does not believe that the author, or anyone else, can say what will be the law of variation of costs for these elements at the pressures and outputs with which he deals. For instance, the author assumes the variation of cost of insulators to be as a cube of the pressure; this assumption may hold with the pressures in use at present, but how does the author know that it will hold when pressures are increased to 150 000 or 200 000 volts? The law of variation of sizes of cost of transformers is also given: how can he tell that it is going to hold for the large powers and high pressures?

The author has figured upon using synchronous apparatus at various points of the line for the purpose of maintaining unity power-factor; the desirability of using such devices as

this is as yet a mooted question, nevertheless they are incorporated in the general scheme when considering the subject of cost of long-distance transmission.

The right of way is taken as simply proportional to the distance of transmission. Evidently a factor depending upon the amount of power should also be included, as well as something to determine the density of the territory which is to be served. This later is a very considerable element.

It has been remarked that the author has paid no attention to the matter of load factor. His assumption of buying power at a fixed figure eliminates the question of cost of generating plant, and in dealing with the transmission problem only the load factor of course may theoretically be neglected. The complete problem should, however, take into consideration the cost of generation of power as well as its transmission and distribution, for in the cost of generation the load factor is one of the most important factors. Strictly speaking, the author is dealing simply with a transmission problem and therefore the matter of load factor may be omitted.

MR. SKINNER: On the author's assumptions of number of units and ultimate output of station, the size of transformer unit required would be 30 000 kw. at 200 000 volts. A single transformer of this capacity would have power approximately equal to that of the first Niagara station. The largest size of transformer with which the speaker has had anything to do is of 3000 kw. capacity. In the manufacture of large transformers one of the most important things to be considered is the mechanical construction of the high-pressure coils. In ordering insulating material for the 3000-kw. transformer, the manufacturers were asked to install larger machinery, as they had no machines of suitable size to manufacture the insulating material required for this size of transformer; size of coils and insulation are not insurmountable obstacles in the way of making larger units, however, as it is possible to piece the various parts that enter into this construction. The speaker admits that at the present time he is unable to imagine the construction of a 30 000-kw. transformer for 200 000 volts. A different general design of transformer must be perfected before the larger sizes can be built successfully.

Another interesting phase of the author's paper is that referring to line insulation. In the opinion of the speaker, the line construction is one of the simplest parts of the problem; this part of the problem can finally be solved by the introduction of steel towers and as few insulators as possible.

H. W. FISHER: Unquestionably this paper is an excellent one and shows much thought and careful mathematical deduction. Without attempting to consider the mathematical side of it, the speaker is of the opinion that the price charged per kilowatt per annum, namely, $34.00, may be higher than that which large users of power would be willing to pay.

In connection with the author's paper, comes very naturally the question: what will be the limiting maximum pressures which can be operated on underground electric cables? The speaker has designed and made short lengths of cable which have withstood 150 000 volts; this also has been accomplished abroad. The lasting qualities, however, of very high-pressure cables can only be determined by operating them under practical conditions for long periods of time. On account of the much greater stress on the insulation near the surface of the conductor, the greatest care has to be used in the design of cables for high pressures. The speaker has made a calculation that will illustrate this point. Suppose there are two cables consisting of No. 6 and 0000 B. & S. gauge solid conductor, homogeneously insulated with 0.1875 in. of good insulating material. If these cables are subjected to 10 000 volts, the stress on the insulation near the conductor will be:

1608 volts per 1/64 for the No. 6.
1138 " " " " No. 0000.

The stresses on the insulation near the lead will be:

485 volts per 1/64 for the No. 6.
627 " " " " No. 0000.

Here we see that the insulation of the No. 6 is subjected to a much greater stress than that of the 0000, and practice demonstrates that it is more difficult to make small conductor than large conductor cables for high pressures. It will also be noted that the insulation of the No. 6 near the conductor is subjected to more than three times the stress on the insulation near the lead. Theory also shows us that if 7.73/64 in. of insulation be applied to the 0000 cable, the insulation near the conductor will be subjected to the same stress as that of the No. 6 above; namely, 1608 volts per 1/64. It would appear, therefore, that a No. 0000 cable insulated with 8/64 in. would be stronger than a No. 6 with 12/64 in. Referring to the first mentioned cable, 14 120 volts on the 0000 cable would produce the same dielectric stress near the conductor as 10 000 volts on the No. 6 cable. For stranded conductors, the stresses near the conductor may be from 20 to 30% greater than those for solid conductors of the same area.

To compensate for this unfortunate condition, two things may be done: first, place near the conductor insulating materials of great dielectric strength; secondly, use insulating material the specific inductive capacity of which will be greatest at the conductor and which will decrease toward the lead cover at the right rate to make the dielectric stress the same all over the insulation. The speaker mentions these few points because they are of the utmost importance in the correct design of high-pressure cables. It is scarcely probable that underground cables will ever be needed to withstand as great pressures as conductors placed on the best insulators. Transmission over long distances will generally be done by the latter plan, but if

the pressures are very high, cables operating from the secondary of step-down transformers will no doubt be used in city limits. Connecting long lengths of aerial conductors to long lengths of cables is not desirable because of danger to the cables from lightning and resonance.

N. J. NEALL: A value should have been inserted in the equations having for its base the probable loss due to interruption of service; uninterrupted service will undoubtedly be more and more demanded, and the proportional cost of interruption of service by lightning-arresters will become greater.

If one were to think of a 500-mile line running, say, from Buffalo to New York, such advanced line construction might be conceived of as to enable one to estimate the cost of maintenance confined to general wear and tear only, but lightning disturbances would certainly be more numerous per line, although possibly not much greater per length of line. Even with simpler lightning-arresters there seems no reason to abandon our theories concerning their functions. For this reason we should consider the recommendations made by Mr. A. J. Wurts—that a line should fairly bristle with discharge-points. This for a high-pressure, high-power line would perhaps mean the employment of section-houses where lightning-arresters could be installed and where section-foremen could live and have apparatus for keeping the line intact. The telephone for such a plant must receive careful installation; it might perhaps prove inadequate and would have to be supplanted by wireless telegraphy. These factors seem worthy of consideration in such a discussion and their bearing on the cost of transmission might assume a value which would materially change the figures given by the author.

DISCUSSION ON "THE MAXIMUM DISTANCE TO WHICH POWER CAN BE ECONOMICALLY TRANSMITTED," AT PHILADELPHIA, PA., JANUARY 9, 1905.

WM. MCCLELLAN: The chief value of the author's paper is its exposition of the methods used. So far as results are concerned, there will be widely differing opinions. The speaker believes that the author has been very liberal except in what might be called the factor of safety. Apparently, three circuits have been provided, each with one-third load capacity. If one of these nine wires should fail only two-thirds of the rated load could be carried. We have, however, plenty of reserve in the converters, etc. In a line projected some time ago there was one extra wire provided for emergencies. The provision in this respect does not seem quite consistent. On the other hand, one must remember that these conductors are of solid copper, one inch and a half in diameter, and not likely to get in trouble except in the land of cyclones.

One should naturally ask, does the paper settle anything definitively? It does tell us definitely that when we have our wire large enough to suit our economic conditions, it will be plenty large enough to suit our electrical conditions. When we heard of Professor Ryan's paper last February, we thought that we might have to increase our wires above economic diameters in order to prevent coronal loss, but we are sure now that we shall not have to do so.

At present there are so few cases where we shall have to transmit such large blocks of power over such distances that the speaker does not believe that the problem is of great interest to many men. A more interesting problem, and one that is becoming more and more prominent, is the combination and development of the many small water-powers in various localities. In many cases these are separately worth little, but taken together, and properly developed, they become dividend earners. Some time ago a commission was examining all the water-powers of New England for this very purpose. It seems almost certain that a great deal of our future transmission work will move in this direction; it will become a part of our future railroad development.

A. B. STITZER: The speaker knows of one company installing some high-pressure apparatus where there are two cables to each station. Either cable is large enough to carry the station's full load, so that if one cable breaks down the load can still be carried with less than eight per cent. drop; the two wires working together will give one half this drop.

Most of the speaker's experience has been with underground transmission work; 13 200 volts is high enough for underground transmission. The insulation is 0.0219-in. paper around each conductor and 0.0219-in. paper over all. In the power house we use 0.375-in. rubber. We were using 0.3125-in. rubber but that is hardly sufficient. The paper is treated with compound; it

is three-conductor cable with 0.09375 inches of lead on the outside.

CARL HERING: The author bases his figures on the present cost of steam power in cities, but it seems to the speaker that there are prospects of reducing the cost of power from coal quite appreciably. Take the case of steam turbines, for instance. A few years ago very little was known about them; with continued improvements the steam turbine has progressed wonderfully. If further improvements are made in the future, electrical transmission of energy may nct be as able to compete then as it is now. It seems to the speaker that there are so few cases where power would be transmitted to such enormous distances as 500 miles that each case must be figured out by itself, and that any such general laws are of little use.

H. A. FOSTER: The speaker believes he is correct in saying that the best steam turbine has not reduced the cost of steam power below the cost at full load of the best of reciprocating engines. Below full load the steam turbine has somewhat reduced the cost of steam power, but at any time a slight increase in the cost of coal will effect all the economies produced by such methods.

Most of us who have had to deal with electric light stations or railway power plants have the matter of the load factor before us all the time. With large water powers the speaker thinks the load-factor of little moment, because there are other loads that come on during the day, many of them that make the load factor nearly 90. A few years ago, at Niagara Falls, the load line could be drawn with a ruler. At that time the lighting load was hardly noticeable.

INDEX OF SUBJECTS.

INDEX OF AUTHORS.

[D indicates discussion and C communication.]